Initial Results from a Study of Climatic Changes and the Effect on Wild Sheep Habitat in Selected Study Areas of Alaska

By Edwin Pfeifer, Jana Ruhlman, Barry Middleton, Dennis Dye, and Alex Acosta

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Abstract

Climate change theorists have projected striking changes in local weather on earth due to increases in temperature. These predicted changes may cause melting glaciers and ice caps, rising sea levels, increasing desertification and other environmental changes which seem likely to affect presumed indicator species as harbingers of more significant changes. Wild sheep, even though they are one of the more successful mammalian taxa since Pleistocene times, exhibit a suite of adaptations to glacier driven environments which may be presumed to render them sensitive to environmental changes. The authors began investigation with these assumptions by comparing changes, as determined by satellite imagery, in glacier extent in our study areas in Denali National Park, Alaska, during the last 30 years. Our findings showed the extent of glacial retreat in Alaska during this time period was approximately 40-50 percent as measured by ablation zone and retreat of terminal moraines. During the first half of this 30-year period, Dall sheep (*Ovis dalli dalli*) populations were stable at historically recorded highs. In the early to mid-1990s, Dall sheep populations in Alaska declined from an historical estimated high of 75,000 sheep to the presently estimated 40-50,000. The declines seemed to be weather related, on the basis of the presumption that lamb survival rates are primarily weather-mediated in Alaska. Changes in local weather appear, at this point, to be correlated with oscillation in the Pacific Current in the Northern Pacific ocean. Of course, changes in local weather affect forage abundance and quality seasonally. In investigating a possible linkage of weather to seasonal forage abundance and quality, we also investigated changes in snow and ice extent and distribution, as well as increased water runoff associated with permafrost and depleted glaciers. Databases were assembled from a wide variety of remotely sensed satellite data, ground-based observations, and historical data bases relating to Dall sheep habitats in selected study areas. Alaska's sheep habitats are typified by long, narrow bands of mountainous uplifts generally arrayed west-to-east, and perpendicular to prevailing south-to-north weather-front movements. Classic Dall sheep habitat occurs on snow-shadowed slopes within these narrow mountainous habitats. On the basis of these data, we offer an explanatory hypothesis relating Dall sheep welfare to weather and climate-influenced nutrition and a monitoring scheme, which should produce data sufficient to test the robustness of this hypothesis. If correlated with population changes, the methods used in our comparative observations may provide long-term monitoring tools for wildlife managers and be applicable in other widely-dispersed wild sheep habitats. If no significant correlations emerge from our modeling exercises, the notion that wild sheep are a sufficiently sensitive species to be seen as an indicator species will have to be reexamined.

Introduction

In Alaska, revenues generated through wild-sheep hunting provide significant funding for wildlife management by the Alaska Department of Fish and Game. Wild sheep also are extremely important to the economies of various central-Asian countries, as considerable revenue is generated from hunting activities. In Asia and Russia, these revenues typically are reinvested in the overall management of wild sheep and goats. Science-based wildlife-management plans are critical in maintaining sustainable populations of wild Dall's sheep (fig. 1).

Figure 1. Dall's sheep on Cathedral Mountain in Denali National Park Alaska.

The U.S. Geological Survey (USGS) Western Geographic Science Center is analyzing long-term effects of glacial retreat and snowfield and permafrost melting in arctic, high-mountain areas of Alaska to determine how these land-surface changes impact wild sheep distribution, population, and welfare. Changes in the habitat can include alteration in vegetation condition, type, abundance, phenology and/or geographical extent, as well as nutritional value and carrying capacity. These habitat changes could be positive or negative, temporary or permanent, unidirectional or fluctuate depending on temperature, precipitation, and glacial-melting trends. For instance, although glaciers, snowfields, and permafrost are thawing at an increased rate, there may be positive effects on the local water supply and habitat. However, once glaciers and snowfields have disappeared, or lost too much volume, and permafrost melting decreases, there can be negative effects on the water supplies. This study investigates the effects of glacial retreat, loss of historical snowfields, and permafrost melting on wild sheep habitat in selected areas of the Alaska Range through analysis of historical (multi decadal) datasets and repeated field observations.

We hypothesize that climatic changes are altering the traditional habitat of high-mountain large mammals, particularly wild sheep. Maintaining healthy wild sheep habitat worldwide requires effective long-term, science-based management. Wild sheep inhabit ecosystems representing ecological extremes, and as such, are well suited to the study of climate change. This group of species may in fact serve as an optimal indicator species for monitoring effects of regional climate change and for understanding the details of key ecological networks influenced by climate variables. The Alaska Range habitat of Dall's sheep (*Ovis dalli dalli)*, named after William H. Dall (USGS Paleontologist) by D.B. Allen who first described the subspecies when he revised mountain sheep taxonomy in 1898, is the primary habitat being examined (fig. 1). Two study areas within the Alaska Range were chosen, one within Denali National Park and the other 70 miles to the east at the headwaters of the Wood River area southeast of Fairbanks, Alaska.

We will characterize wild sheep habitat by using a multi resolution, multi temporal suite of remotely sensed data linked to contemporary and historical ground observations. Remotely sensed data, including satellite imagery at multiple resolutions and historical aerial photography, will be used to evaluate decades of landscape and vegetation change related to glacial and snowfield retreat and permafrost melting. Repeated ground-based observations are being collected to characterize sheep habitat in the selected study areas to and provide ancillary information on the health of the habitat. Ground-based vegetation transects are being used to aid in vegetation mapping from satellite imagery, while water samples from snowfield melt, glacial melt, and springs are being collected and analyzed for nutrient levels. Dall's sheep feces samples are being collected and analyzed for FN (fecal nitrogen), fecal DAPA (diamino pimelic acid), and forage-species composition. Fecal analysis will be used to assess the nutritional value, digestibility, and species composition of the wild sheep forage. Analysis of historical satellite-image datasets will be used to provide information on the vegetation response to climatic change during the previous decades and will guide our modeling efforts to estimate future effects of climate change on wild sheep habitat.

The distinctive landscapes defined through analysis of remotely sensed data will be coupled with the water, plant, and fecal analyses to attach measures of nutritional value, habitat value, and habitat health to each landscape type. The combination of satellite-based products, ground observations, and historical data on sheep distribution and population will be instrumental in the development of baseline datasets and predictive models that can become valuable tools for wildlife managers. If modeling efforts are successful in the Alaska study areas, future research plans include expanding the geographic scope to include wild sheep habitats in central Asia and possibly far-eastern Russia.

Purpose and Scope

The purpose of this research is to produce a set of decision-support management tools and habitat models that can ultimately be used in the development of sustainable-habitat and wildlife-management plans. Techniques will be developed to characterize historical and current land-cover change and the effect on wild sheep populations owing to glacial retreat and loss of snowfields and permafrost in high-mountain and arctic regions of Alaska. Predictive models will be developed based on current and historical data and field observations to forecast future habitat response. Analyses will be performed to determine the environmental consequences of continued glacial retreat and snowfield and permafrost melt in the study areas and its effects on the local wild sheep populations.

Specifically, some of the questions this research hopes to answer are:

- What is the impact of observed glacial retreat/melting, snowfield loss, and permafrost melting on Dall's sheep habitat?
- What changes in the vegetation of the wild sheep habitat are taking place as a result of climatic changes?
- Are nutrient levels in Dall's sheep forage in the study areas increasing or decreasing over time as a result of these changes?
- Are woody plants and tundra vegetation moving upslope?
- Can predictive habitat models be developed to anticipate future changes on the basis of estimates of continued climate change?

Methodology

A wide variety of remotely-sensed data, ground-based observations, and existing historical databases are the primary sources from which land-cover change information for the study areas is derived. The varying spatial and temporal resolutions of Landsat, MODIS, and Quickbird imagery are all being leveraged to map and assess glacial and vegetation changes within the selected study areas. These remotely sensed data are used along with ground-based observations (both historical and contemporary) to gain information about general habitat condition, quality and distribution, vegetation phenology, favored habitat of wild sheep populations in the study areas, and how this habitat may be changing over time.

Coarse spatial resolution AVHRR and MODIS satellite imagery is being used to track vegetation phenology at high temporal resolution (daily) over large areas. Analysis of vegetation phenology provides information on the integrated response of plant species to environmental conditions (including climate) as reflected in the timing, intensity, and duration of vegetation greenness. Moderate resolution Landsat satellite imagery has been employed to determine the summer minimum glacial and snowfield aerial extent for each year between 1979 and 2007 for a portion of the Alaska Range in Denali National Park. These data are supplemented with historical aerial photography, topographic maps, and historical reports and photographs that provide information on snow and ice distribution prior to availability of satellite data in the 1970s. Landsat data are also used to map general vegetation-community types.

Quickbird satellite imagery is being used to capture vegetation pattern and structure at submeter scales, which enhances mapping of generalized vegetation types, including woody versus. non woody vegetation. By integrating information from the suite of multi temporal and multi resolution satellite data we can derive various phenological, spatial and structural metrics to define and characterize the different landscapes that constitute sheep habitat.

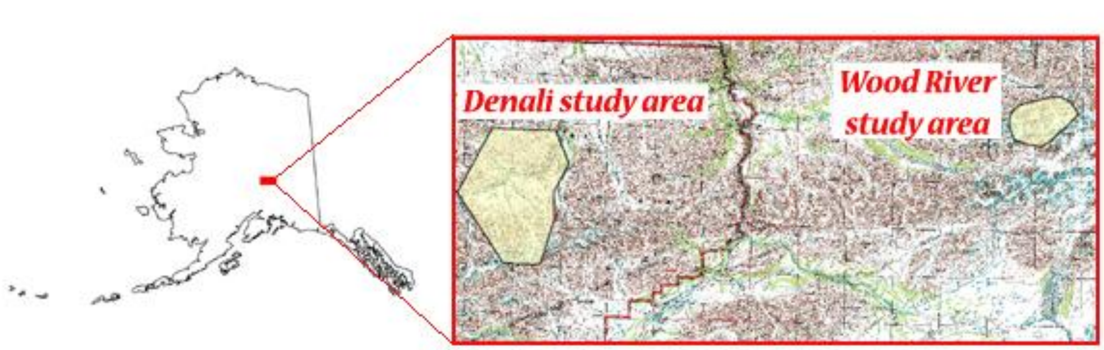
Supplemental datasets also are being developed from field observations and historical collections to further characterize habitat quality in the study areas. Geographic positioning system (GPS) points are collected along vegetation transects and within distinct vegetation types to aid in developing vegetation maps of the Denali study area. Historical aerial photography is being compared to recent imagery and existing Denali National Park vegetation maps to detect and evaluate vegetation changes in sheep habitat, such as suspected up slope encroachment of woody plants. Water samples are being collected from snowfield melt, glacial melt, permafrost melt, and springs and analyzed for nutrient levels. Dall's sheep feces samples are being collected along with associated GPS location data, and analyzed for fecal nitrogen and fecal DAPA, both on an ash-free and a dry matter basis. Diet composition analyses also have been performed on the fecal samples to give an indication of the wild sheep's preferred diet. The fecal analysis helps assess the nutritional value of the wild sheep forage and how value this might affect the stress level of the wild sheep. Current and historical climate data also is being examined and will be woven into the development of predictive models and used for understanding historical observations and newly created datasets.

Change detection datasets, multi temporal NDVI, and other products will be generated from the Landsat, AVHRR, and MODIS data to construct baseline phenology datasets and to analyze phenological changes over a multi decadal period. Information derived from satellite data will be coupled with ground data to develop products that assist in determining variability in land/ice/snow extent and assessing the condition, quality and extent of the wild sheep habitat. Once a reliable set of baseline data has been collected and analyzed, models will be developed to predict changes that could occur in the quality and nutrient level of the wild sheep habitat and forage due to changing climate conditions. Subsequent collection of remotely sensed data will be used to map changes in these landscapes through time. Such an analysis permits evaluation of the changes in the overall quality of wild sheep habitat based on the inferred nutritional value of each vegetation type, and provides a means to monitor habitat quality through time.

Study Areas

Two initial study sites were selected in Alaska: one within Denali National Park, and the other 70 miles east of Denali National Park along the north slope of the Alaska Range, at the headwaters of the Wood River (fig. 2). Major factors considered in selecting these sites included accessibility, known Dall's sheep populations, availability of prior research data, proximity to moderate-to-small size glacial systems, and conditions that would enable comparison between an undisturbed wild sheep population and a heavily managed and hunted population.

Figure 2. Location map of the two main study sites in Alaska.



The study area within Denali National Park has an approximate center latitude/longitude of 63.52N and 149.76W. Elevations within the study area vary from approximately 764 m (2,506 f) to 2,417 m (7,930 ft). The Wood River study area is centered at approximately 63.67N latitude and 147.62W longitude. Elevations here are higher than those in the Denali site, ranging from approximately 1,280 m (4,199 ft) to 2,473 m (8,114 ft). Detailed locations of both study sites are shown in figures 3 and 4.

Field work was initiated in 2007 at the Denali study area, performed at both the Denali and Wood River study sites in 2008**,** and continued at Denali in 2009. In 2008 and 2009, fecal-analysis samples were collected by project collaborators at additional sites located in the Wrangell-St. Elias National Park and Preserve, Alaska. Data from this third area will be further studied in comparison with the other two study areas.

Figure 3. Detail of the Denali National Park, Alaska, study site shown using (**A)** topographic map and (***B***), Landsat TM satellite image.

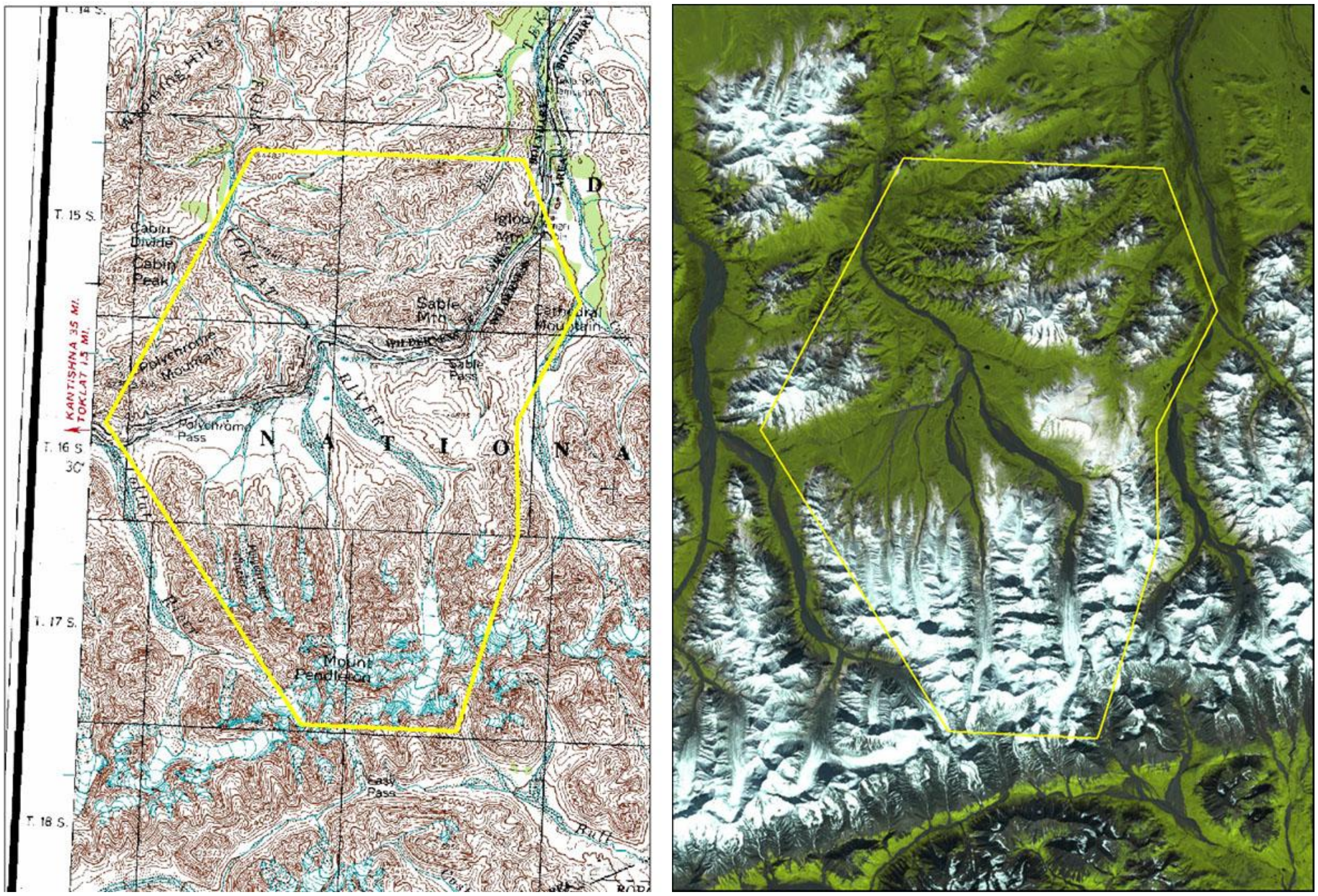
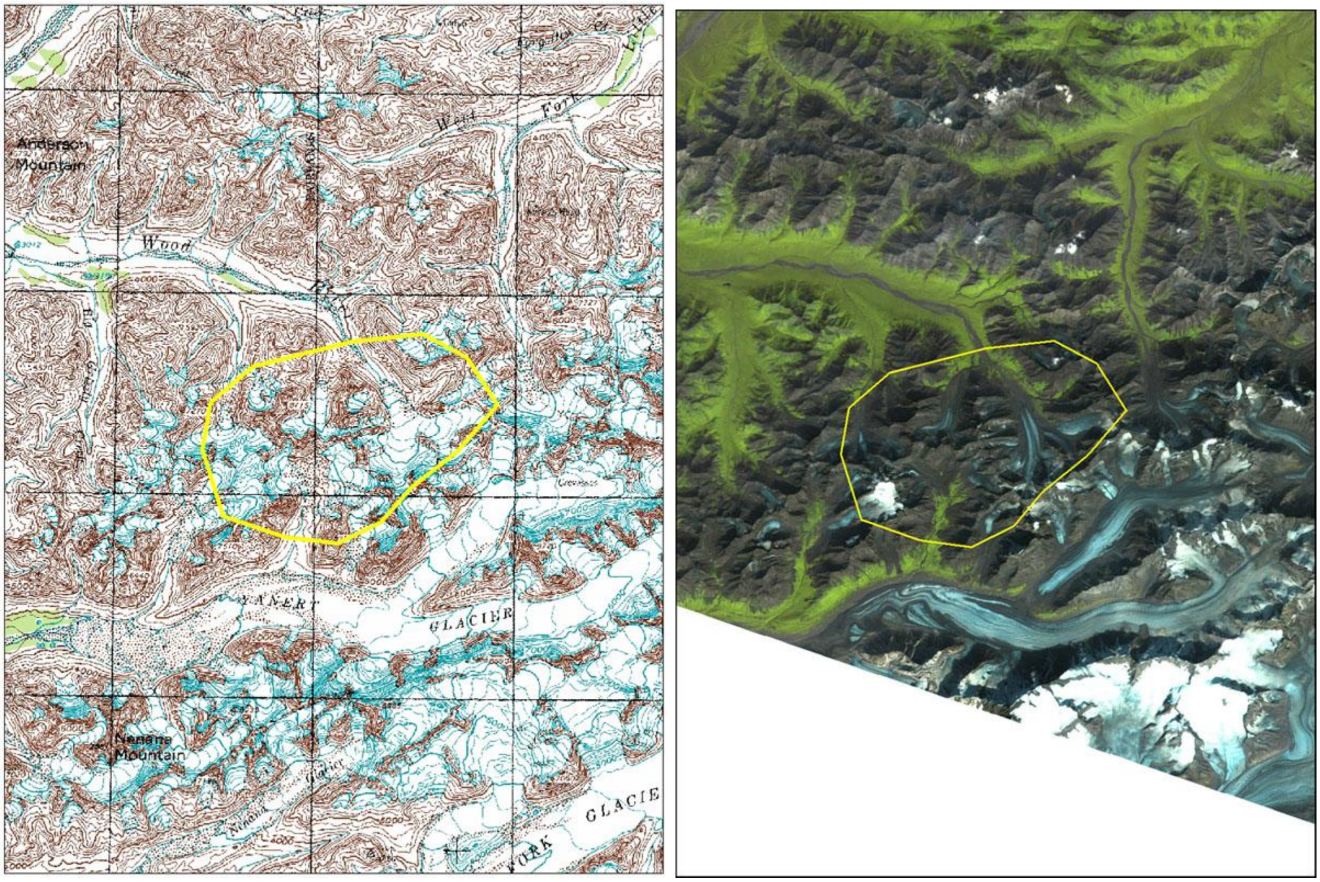


Figure 4. Detail of the Wood River, Alaska, study site shown using (**A**) topographic map (**B**) Landsat TM satellite image.



Dall's Sheep Habitat

Valdez states that "The most important goal of wildlife management is to maintain habitats that provide the requirements of individual species" (Valdez, 1982, p. 60). For Dall's sheep these requirements include adequate space and sufficient high-quality forage that provide necessary nutrients. Such environments sustain healthy populations and "are critical to the survival of all wild sheep" (Valdez, 1982, p. 60).

Dall's sheep habitat typically occurs on the upper slopes of mountains. These traditional foraging areas consist of higher-elevation grasses and sedges adjacent to steep, rocky slopes utilized for escape from predators (figs. 5 and 6). Lower slopes are usually covered with woody plants and are not desirable habitat. In the Alaska Range, Dall's sheep are found in high alpine meadows that have abundant forage, adjacent steep, rocky terrain, and varied slope aspects that allow movement based on optimum weather conditions (Heimer, 1999, p. 48). Heimer believes that prime Dall's sheep habitats are found "on the 'rain or snow shadowed' sides of relatively narrow mountain ranges, which lie across the paths traced by winter storms as they move inland from the northern seas. The best of prime habitats are found adjacent to low passes or wind channels, which accelerate winds through the mountains and remove snow from Dall's sheep winter food." (Heimer, 1998, p. 71).

Understanding how climate change and glacial retreat may be affecting Dall's sheep habitat is critical to the development of judicious management programs. One possibility is that weather patterns, those influenced by geography or topography, are the main factors that determine suitable Dall's sheep habitat (Heimer, 1998, p. 71 ; 2000, p. 27-28). Another hypothesis is that glacial retreat and advance are the primary drivers that influence wild sheep distribution and population quality (Geist, 1971).

Figure 5. Close-up of alpine tundra vegetation in Denali National Park, Alaska.

Figure 6. Dall's sheep on a steep slope in Denali National Park Alaska.

Dall's Sheep Research in Denali National Park — Then and Now

A rich body of historical wild sheep observations and research forms an important and invaluable resource we are compiling for this study. In the late 1800s and early 1900s wild sheep research primarily involved the collecting of specimens by self-styled naturalists. These naturalists, often called gentlemen naturalists, performed research and collecting expeditions into remote areas throughout North America and often throughout the world. The specimen's body and horn dimensions were recorded, along with occasional weight measurements or body-weight estimates. Photographs played an important role in documenting the specimen.

Present-day wild sheep research still involves many of these earlier techniques; however, modern work usually includes a wide variety of research techniques and scientific disciplines. Biological aspects are central to present day wild sheep research and include tissue sampling and analysis, aging by analysis of tooth structure and horn growth rings, feces sampling and analysis for nutrient levels and favored forage, and Deoxyribonucleic acid (DNA) analysis. DNA samples are utilized increasingly utilized for a wide range of analyses, including assessing natural patterns of genetic diversity and obtaining information on parasite loads in wild sheep populations (Roffler and others, 2009). Remotely sensed images can be used for evaluation of ecosystem condition and forage quality, particularly when coupled with the results of biologic samples. Use of remotely sensed data, such as satellite imagery and aerial photography can be used to evaluate phenological changes in, and condition of, wild sheep habitat. Ground-based sensor systems that measure climate variables (wind speed and direction, air temperature, humidity, precipitation amounts, and snowfall depth) often are used to detect and monitor valuable environmental data pertinent to sheep habitat. In addition, water sampling and testing for nitrogen, as well as monitoring other potential indicators of sheep health and forage condition, also are utilized.

Charles T. Sheldon

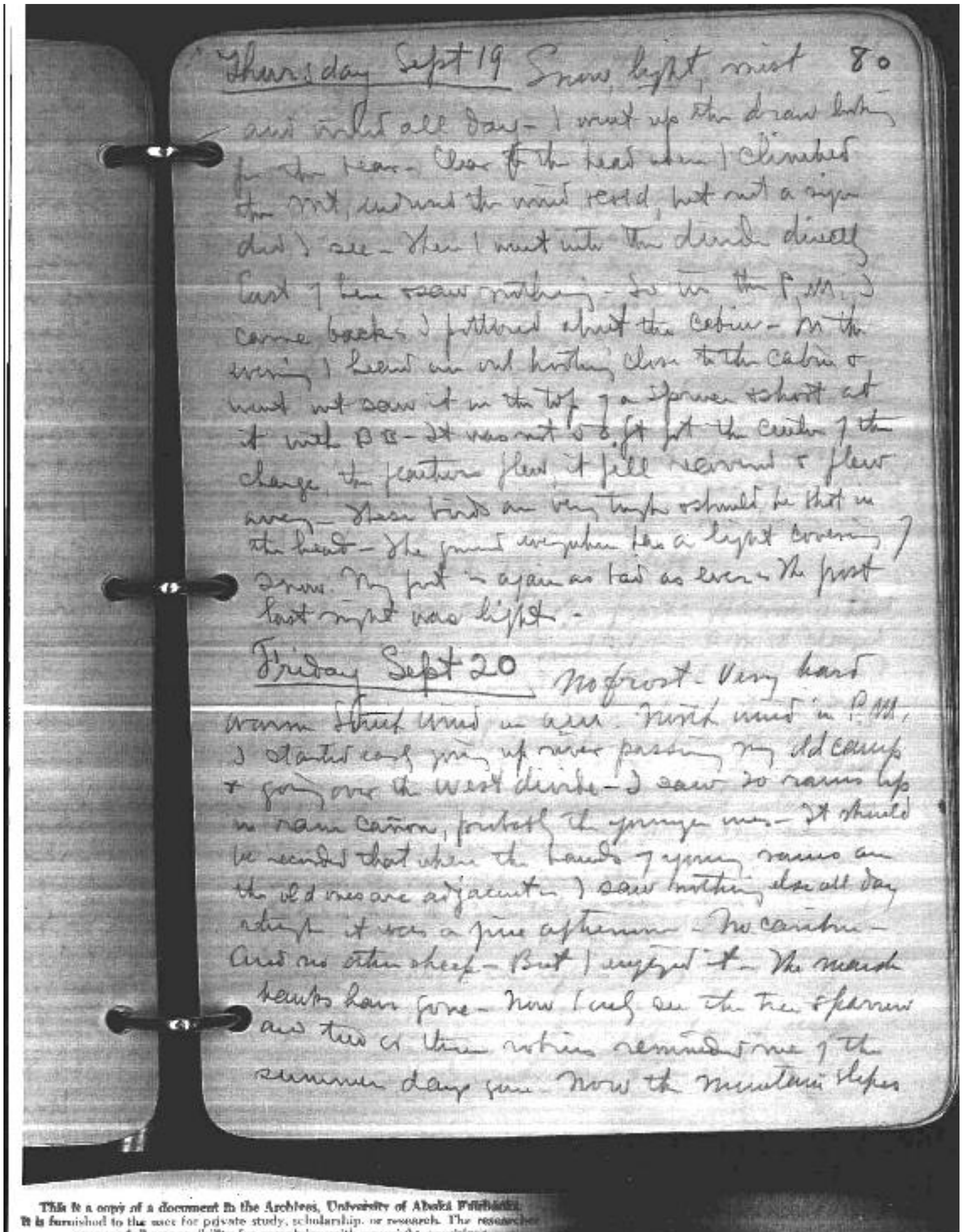
Sheldon was one of a group of early 1900s self-styled naturalists who performed research and collecting expeditions into remote areas throughout North America and beyond. Contemporaries of Sheldon include, but are not limited to: C. Hart Merriam, William T. Hornaday, Daniel Trembly MacDougal, Godfrey Sykes, and John J. Audubon. Even Theodore Roosevelt and the Roosevelt brothers got involved. Naturalists often personally funded their research and collecting activities, or acquired funding from museums, zoological societies, and conservation organizations. More often than not, they were prolific writers who kept detailed field notes and photographic records. Sheldon, however, focused more than any of his contemporaries on the wild sheep of the far north.

Charles Sheldon was born on October 17, 1867, and died in 1928. He was on the Board of Directors of the American Forestry Association, Vice-President of the Boone and Crockett Club, Trustee and member of the Executive Committee of the National Parks Association, Honorary Life Member of the Committee on Research of the National Geographic Society, and Director and Chairman of the Executive Committee of the Wild Fowlers League. Sheldon also was associated with the American Ornithologist Union, American Society of Mammalogists, Biological Society of Washington, Zoological Society of New York, American Game Protective Association, Izaak Walton League in America, Cosmos Club, and Explorers Club of New York.

Sheldon kept detailed photographic records and field notes documenting his day to day activities and data collection during his exploration and research activities (fig. 7). He was a prolific writer, having authored the following books: The Wilderness of the Upper Yukon, 1911; The Wilderness of the

North Pacific Coast Islands, 1912**;** The Wilderness of Denali, 1930 (published posthumously)**;** and a number of manuscripts including The Wilderness of Desert Bighorns and Seri Indians in 1912.

Figure 7. A page from Sheldon's log of 1907 (courtesy of University of Alaska Fairbanks; Alaska and Polar Regions Collections; Elmer E. Rasmuson Library).



Thursday Sept 19 Snow, light, mist 80
and wind all day - I went up the draw looking
for the bears. Clear of the head when I climbed
the mt, noticed the wind veered, but not a sign
did I see - then I went into the divide directly
east of here saw nothing - So in the P.M. I
came back & pottered about the cabin - In the
evening I heard an owl hooting close to the cabin &
went out saw it in the top of a spruce & shot at
it with BB - It was not 6 ft but the center of the
charge the feathers flew it fell [illegible] & flew
away - These birds are very tough & should be shot in
the head - The ground everywhere has a light covering of
snow. My foot is again as bad as ever. The frost
last night was light -
Friday Sept 20 No frost - Very hard
warm [illegible] wind in [illegible] North wind in P.M.
I started early going up river passing my old camp
& going over the west divide - I saw 20 rams lying
in ram canyon, probably the younger ones - It should
be recorded that where the bands of young rams are
the old ones are adjacent - I saw nothing else all day
though it was a fine afternoon - No caribou -
And no other sheep - But I enjoyed it - The marsh
hawks have gone - Now I only see the tree sparrows
and two or three robins reminding me of the
summer days gone. Now the mountain slopes

Sheldon's Research in the Mt. McKinley Area

Charles Sheldon first studied Dall's sheep in the Denali area from July to September 1906, but he soon determined that three months were not sufficient to adequately study Dall's sheep habits. Furthermore, travel to the far north from the east coast was not trivial, often taking several months and involving transport by train, ship, wagon, small boat, and horses. Because of the length of time to get to the field area, expeditions necessarily covered long periods of time.

Sheldon returned to Denali in the summer of 1907 to spend approximately 10 months, primarily in the area of the Toklat River and East Fork of the Toklat River. He focused his activities in an area roughly bound by Stony Creek on the west, Stony Hill, Stony Dome, and Divide Mountain on the south, Polychrome Mountain, Cabin Peak, and the East Fork of the Toklat River on the east, and Wyoming Hills on the north in what is now Denali National Park and Preserve (fig. 8). He worked most often alone, occasionally accompanied by Harry Karstens (whose cabin still remains near the East Fork Visitor Center) or an occasional packer.

Figure 8. Photographs from Sheldon's time in Denali in 1907 (courtesy of Shelburne Museum, Shelburne, Vermont).

Sheldon's research focused on documenting numbers of sheep (and other large mammals) and their habits in given study areas, numbers of mature rams versus ewes and lambs, and general habitat condition and favored areas. He also kept detailed temperature and weather records. Sheldon's research included some activities that would now be considered inappropriate, such as the collection\ of rather large numbers of Dall's sheep and other large and small mammals. Measurements were taken of the height at the shoulder, body girth, and estimated weight, and included a visual evaluation of the general health of the specimen. The remoteness of the area made the collection of tissue samples and stomach contents for analysis impractical.

It is worth noting that Sheldon preserved the skins, horns, and often the major skeletal bones of animals collected for donation to museums, universities, and other scientific institutions for further research and preservation. The recipient museums included the prestigious American Museum of Natural History in New York and Chicago Field Museum, among others.

Sheldon was a driving force in having the Mt. McKinley area established as a national park. At Sheldon's urging, Director Stephen Mather appointed Harry Karstens as the first park superintendent, thereby repaying debts to his faithful packer (Rawson, 2001).

Research Activities (2007-2009)

The majority of current research and field-data collection activities (Dall's sheep feces, water samples, vegetation samples, and vegetation transects) is being done by USGS personnel from the Western Geographic Science Center. This work includes processing remotely sensed satellite data (Landsat, AVHRR, MODIS, and Quickbird) to analyze habitat change and condition, glacial and snowfield change, and to develop derivative products. Other contributors include students in the Alaska Wildlands Program at the Wrangell Mountain Center, who collected vegetation information and Dall's sheep feces samples in the Mill Creek Valley area of the Wrangell Mountains, and Gretchen Roffler, USGS, Alaska Science Center who collected Dall's sheep pellets at other locations in the Wrangell Mountains.

Research efforts to date have focused on collecting field data, processing Landsat data for the Denali and Wood River study areas, and utilizing Landsat and other remotely-sensed imagery to identify and map vegetation types, as well as the current and historic extent of glaciers, and permanent snowfields in the study areas. These products are further explained below. Development of predictive modeling is planned to begin early in 2010, and will seek to forecast the extent and quality of future wild sheep habitat changes under various climate change scenarios.

Changes in Glacial and Snowfield Extents

We hypothesize that Dall's sheep distribution, population, and habitat quality are significantly impacted by glacial advance and retreat (fig. 9). Glacial retreat can result in upslope movement of woody plants (aspen/poplar, willow, and fir) and can seriously impact favored habitat and forage nutrition (Geist, 1971). Optimum Dall's sheep habitat is free of woody plants, and has substantial forage areas, typically within sight of glaciers, and steep rocky slopes and cliffs providing escape terrain.

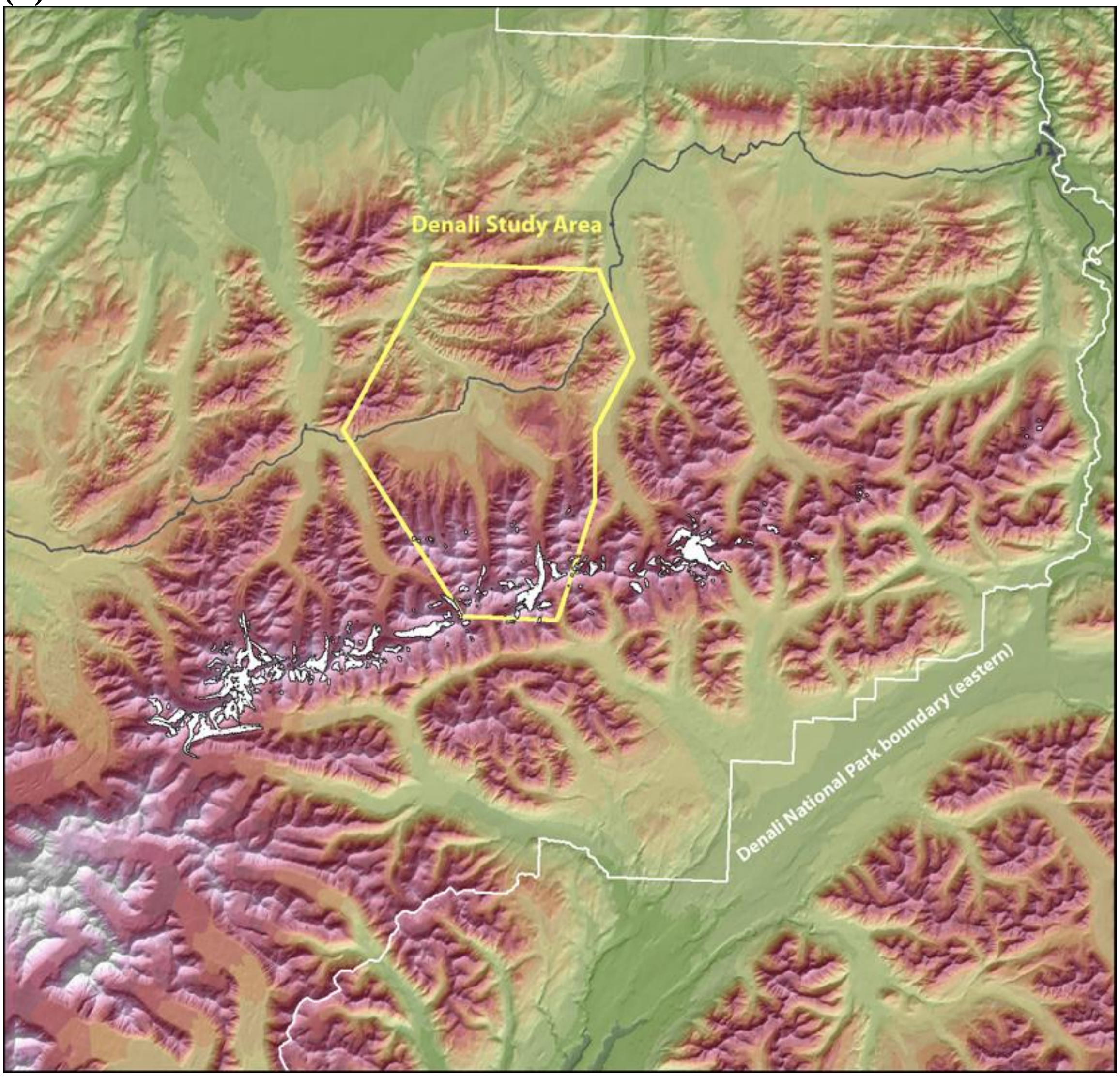
Figure 9. Large glacier in Denali National Park, Alaska study area.

Landsat images were analyzed to map changes in glacial and permanent snowfield margins from 1979 to 2007 in an area of the Alaska Range. The yellow star on the Alaska map of Fig. 10A indicates the general study area, and Fig. 10B shows this area of the Alaska Range in more detail, and in relationship to the Denali study area. Glaciers are shown in white and indicate the extent of the area studied. Glaciers outside of our immediate Denali study area were included to enable a more statistically significant sampling of glacial change. All glaciers and permanent snowfields mapped in this expanded area belong to the same moderately high elevation, similar trending, and nearly continuous ridgeline as the glaciers found in the study area.

Figure 10. (A) National Park Service map showing general location of glacial study, (B) Colorized shaded relief image of the glacial extent studied, shown in relation to the Denali National Park study area.

(A)

(B)



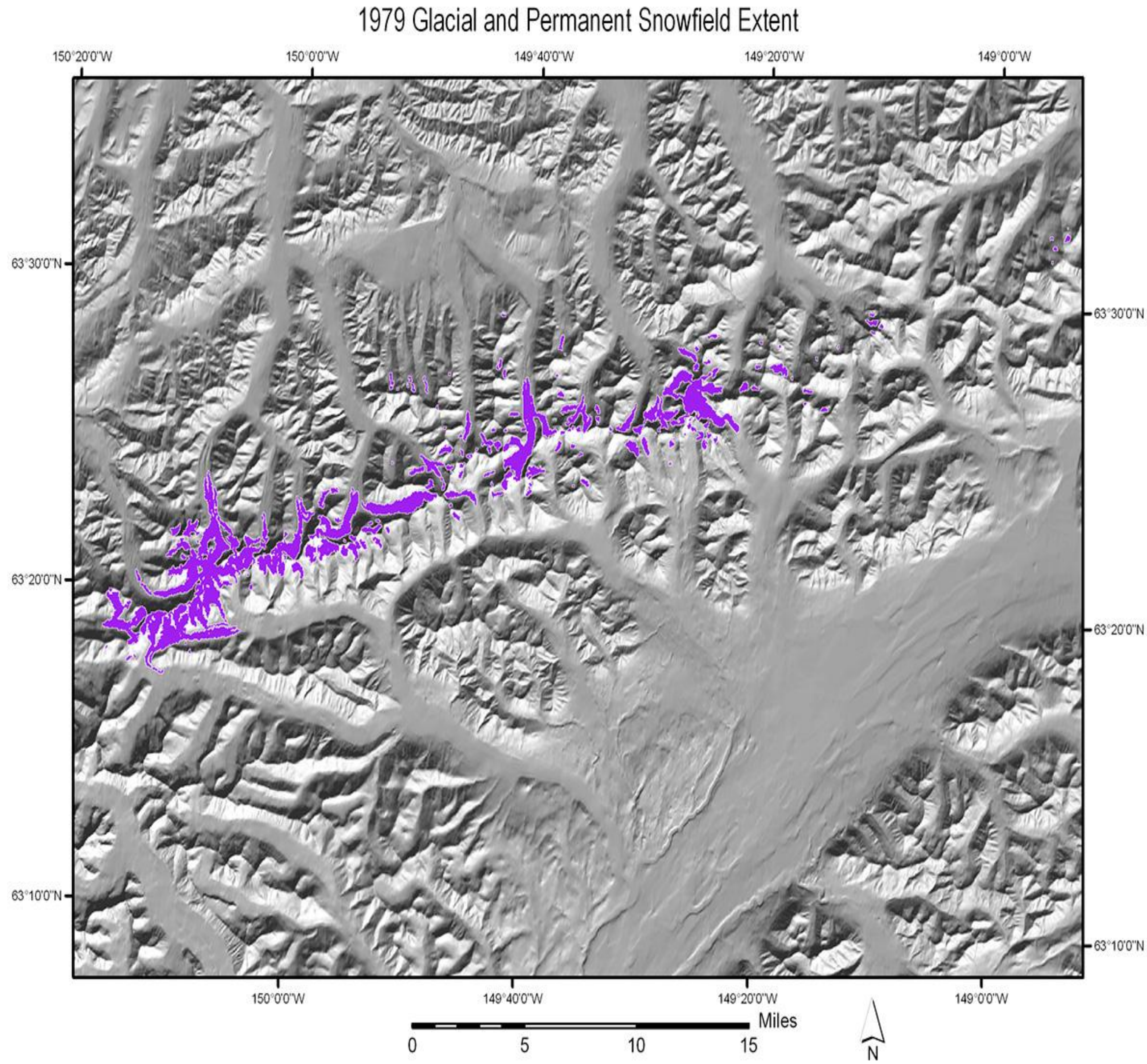
Glacial and permanent snowfield extent was mapped using Landsat MSS (August 24, 1979) and TM (2006-2008) satellite data. Multiple Landsat TM dates were needed to allow for cloud-free views of all the glaciers and snowfields. The primary image date used to produce the 2007 map was August 28, 2007, with additional image dates used on a limited basis. We selected summer images to capture the yearly minimum ice and snow extent for each year.

To produce these maps, a hybrid method was employed using a combination of manual and automated techniques. Several predominantly automated image classification approaches were attempted initially and resulted in less than ideal maps. The combination of clouds, terrain and cloud shadows, haze, and recent snow greatly limited the effectiveness of these automated techniques. Manual mapping methods allow for greater precision along glacial boundaries because the human interpreter can incorporate all elements of interpretation (color, tone, brightness, texture, spatial reference, and logic) into mapping decisions.

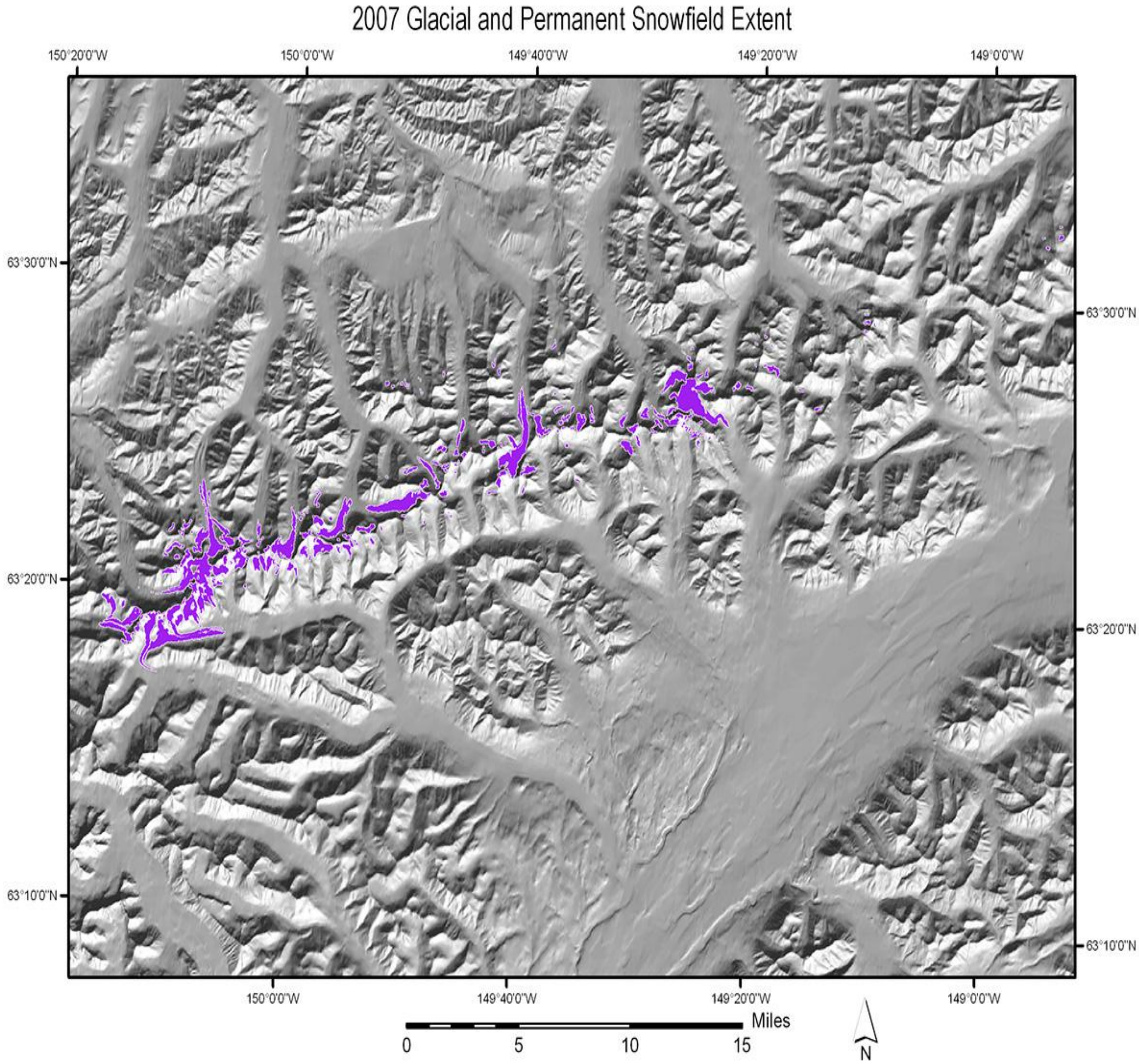
The purple areas on figure 11 show glacial extent in 1979 and in 2007. The blue and cyan colors in Figure 12 represent the glacial ablation and accumulation zones, respectively. The ablation zone is the area of a glacier below the snowline, where annual loss of snow/ice through melting, evaporation, and sublimation exceeds annual gain of snow/ice on the surface. The area of a glacier above the snowline, where snow/ice accumulates and exceeds the annual loss from melting, evaporation, and sublimation, is known as the accumulation zone.

Figure 11. Glacial and permanent snowfield extents shown in (A) 1979, and (B) 2007.

(A)



(B)



Our analysis showed that from 1979 to 2007 the mean elevation of the glaciers and permanent snowfields increased from approximately 1,821.8 m to 1,862.3 m (5,977 to 6,110ft), an increase of 40.5 m (133 ft). During this same time the surface area of the mapped glaciers and permanent snowfields changed from 104.2 km^2 to 55.0 km^2, a 47-percent decline. These surface-area calculations take topography into account. Keep in mind; the glaciers and permanent snowfields along the moderate elevation ridgeline that was mapped occupy generally lower elevations than most of the other glaciers in Denali National Park. These lower elevations are more strongly affected by warmer temperatures, enhancing the ecellarating retreat. Therefore, the 47 percent decline in area is likely a maximum average value for glacier retreat and permanent snowfield reduction in Denali National Park. Further analysis is underway to compare these results with other reported studies.

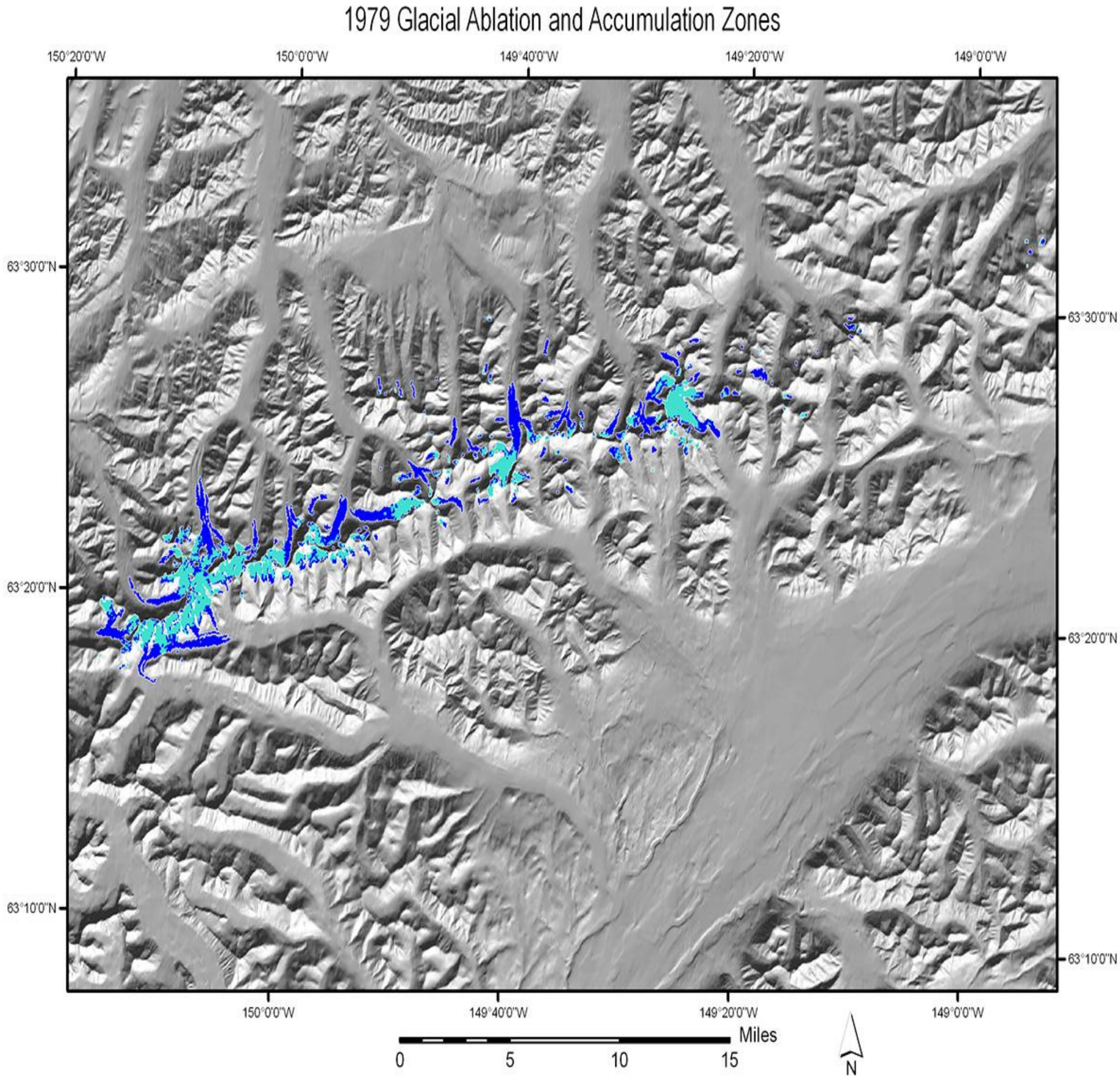
Visual and textural differences between snow, firn, and glacier ice allows differentiation of the accumulation zone, with its firn and snow surface, from the ablation zone, with its patches of exposed blue/cyan glacier ice. Firn is partially compacted and recrystallized snow from past seasons, is intermediate in density**,** and has other characteristics that enable it to be visually distinguished from the glacial ice, even from satellite altitudes. This differentiation can most easily be made during the minimum snow cover period in central Alaska (mid-August to early September) when snow does not obstruct the satellite's view of the underlying firn and glacier ice. Each year can be different, however, depending on the amount and timing of snowfall.

In figure 12, the ablation zone is shown in dark blue and the accumulation zone is shown in cyan. These images show a 57-percent decline in the ablation zone and a 41-percent decline in the accumulation zone from 1979 to 2007. The historical ablation zone (circa 1979) seems to have been more heavily impacted than the historical accumulation zone (1979) by the changing climate. This makes sense as the number of days above freezing, and temperature differential above-freezing for each of those days, becomes even greater under a warming climate. Therefore, the ablation zone is now exposed to an even greater duration, quantity and magnitude of above freezing temperatures then before. Relative to the ancestral accumulation zone now below the elevating snow line, the former ablation zone receives a significantly greater heat budget and, consequently, would be expected to disappear at a faster rate. Further analysis is being done to compare these results with other published data.

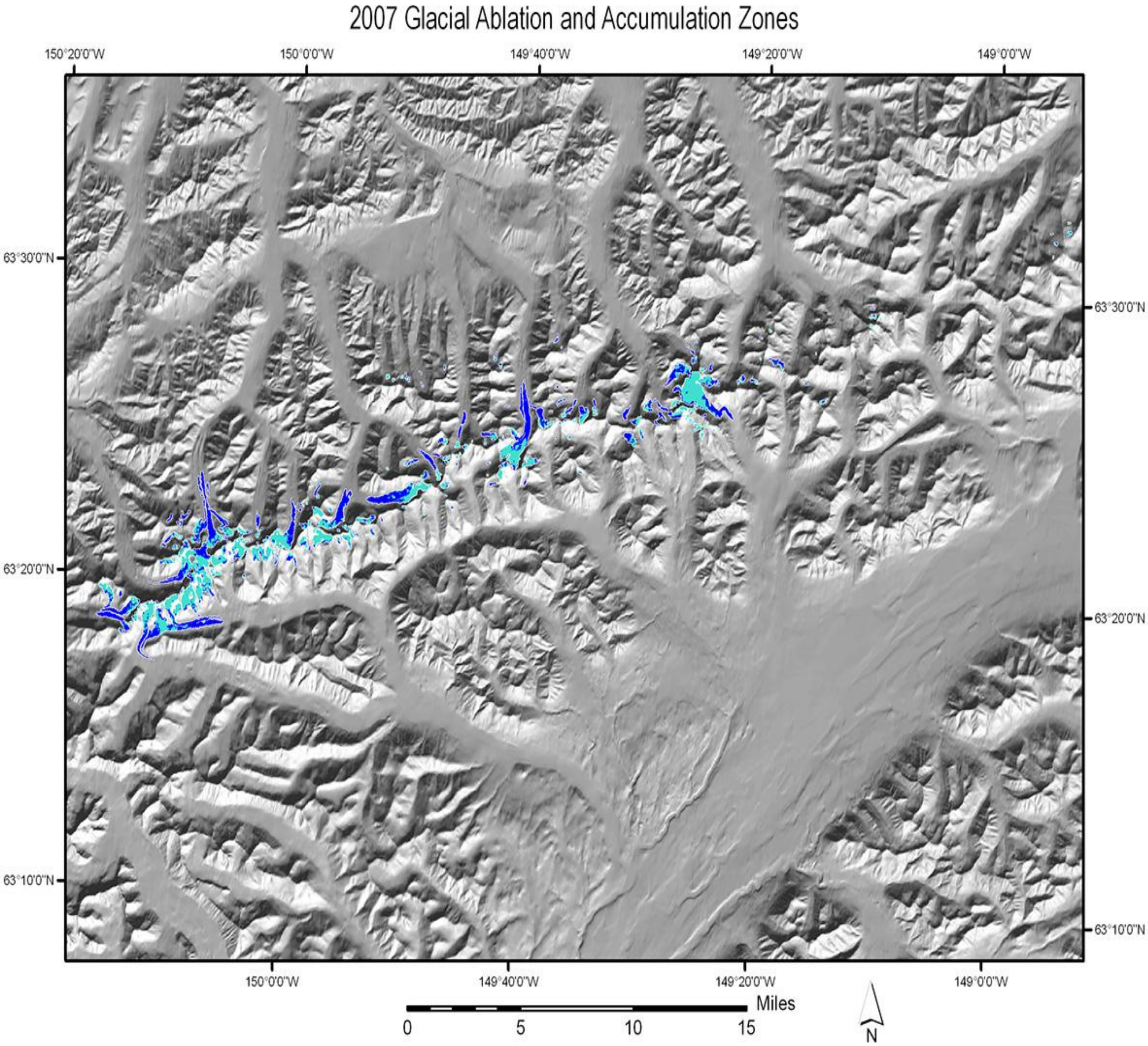
To create the glacial maps displayed in figures 11 and 12, the following core image dates were used: August 24, 1979 (Landsat MSS), and August 28, 2007 (landsat TM5). Two additional TM5 image dates (September 3, 2006, and August 23, 2008) were used to supplement the 2007 Landsat imagery, as clouds covered a significant portion of the August 28, 2007, image.

Figure 12. Ablation (dark blue) / Accumulation (cyan) zones in 1979, and 2007.

(A)



(B)



Fecal Analysis

Wild sheep feces (pellets) are being collected and analyzed for nutrient value, digestibility, and vegetation-species composition of the wild sheep forage (fig. 13). The results will be used to quantify the overall nutritional value of the forage and, thereby, inferred habitat quality of the landscape from which the samples were collected.

Figure 13. Close-up of Dall's sheep pellets.

DAPA and FN Analysis

Both diamino pimelic acid (DAPA), a unique amino-acid residue of rumen bacterial fermentation) and FN (fecal nitrogen) are used as nutritional indicators to track the relative changes in the nutritional quality of diet over time (Wehausen, 1992). These indicators allow one to see when there may be a nutritional deficit in an area or herd, or to compare different herds in different areas. Utilizing the relationship between DAPA and diet quality is a direct, inexpensive method that allows a herd to be monitored for nutritional well-being without requiring the death of the animal. As it passes through the digestive process**,** DAPA is not absorbed by the animal, but is passed out in its feces.

According to Bruce Davitt of the Wildlife Habitat Nutrition Lab at Washington State University, this new technology is based on the knowledge that:

- More than 80% of a grazing or browsing ruminant's diet digestible energy is directly or indirectly attributed to bacterial fermentation in the rumen.
- Most of the bacteria species which digest forage contain an amino acid (DAPA) in their body wall.
- DAPA is found only in the cell walls of these rumen bacteria (and in some blue-green algae), but not in the forage plant tissue or big game animal tissue.
- DAPA comprises a rather consistent 4.1% of the bacterial mass on a dry matter basis (Bruce Davitt, written commun., 2007).

We assume that the greater the amount of digestible energy available through bacterial fermentation in the rumen means more DAPA-bearing bacterial mass is present and is, therefore, excreted. Diet digestible energy changes seasonally, as reflected by annual cyclic fluctuations of DAPA profiles. Measurements of digestible energy are lowest in winter, when diet quality is low (possibly indicating limited or lower-quality forage available), and higher during the forage growing season, when diet quality is best. Herds with higher DAPA profiles would be considered in better condition than those with lower DAPA profiles.

DAPA values (dry-matter basis) often run from 0.20 mg/gm on the low end to slightly more than 1.0 mg/gm during the most nutritious periods. This assumes normal levels of ash. FN values (dry-matter basis) often run from 1.0 percent FN on the low end of the nutritional scale to about 3.0 percent FN on the high end of the scale. DAPA follows the digestibility (particularly energy digestibility), and FN tracks nitrogen (protein intake) of the forage eaten.

Bighorn sheep and mountain goats often consume soil to get minerals, which accounts for the percentage of total ash. Ash can be considered as filler. To account for this, the sample weight is reduced by the ash percentage, which results in higher DAPA and FN values. The original sample, which has not been compensated for ash content, is considered as being on a dry-matter basis. Once the ash has been compensated for, the results are considered as being on an organic-matter basis (or ash free). If sheep frequent salt licks, the inorganic portion can reach half the sample and affect FN and DAPA results unless corrected for high-ash situations. Our sample analyses results are shown for both the dry matter and organic-matter (ash free) basis.

Dall’s sheep pellet collection began in Alaska in 2007, with one population sampled. Sample collections increased substantially in 2008, with seven populations sampled (fig. 14). Because 2007 and 2008 are the first years pellets have been collected and analyzed, these results will become a baseline from which to evaluate future data.

Figure 14. Collecting sheep pellets on Cathedral Mountain in the study area at Denali National Park, Alaska.

2007-2008 Fecal Analysis Results

In 2007**,** samples were collected from five different locations on Cathedral Mountain in Denali National Park. In 2008 Dall’s sheep pellets were collected from 16 different locations in Denali: six on Sable Mountain and ten on Cathedral Mountain. Samples also were collected near the Wood River study site in 2008. Also in 2008, students in the Alaska Wildlands Program at the Wrangell Mountains Center, led by Dr. Megan K. Gahl (Director, Alaska Wildlands Studies Program) collected seven samples in the Mill Creek Valley area. Twenty additional samples from other locations in the Wrangell-

St. Elias Mountains and Chugach Mountains were collected by Gretchen Roffler, USGS, Alaska Science Center.

Sheep pellets from both years were analyzed by the Wildlife Habitat Nutrition Laboratory at Washington State University for FN, DAPA, and a food-habits profile. The food-habits profile for the 2007 samples identified the sheep's diet down to the plant genus or species level and is summarized in table 1. Understanding dietary composition allows us to focus on changes within the sheep's preferred vegetation. Dietary composition of the 2007 Cathedral Mountain samples (Denali study area) show that although there were distinct differences between the various samples, grasses, sedges, and rushes accounted for approximately two-thirds of the total diet indicated by these samples. The detailed diet composition analysis for the 2007 samples can be found in appendix 1. Diet composition analysis of the 2008 samples is expected to be available by December 2009.

Table 1. Dietary composition of 2007 Cathedral Mountain fecal samples (Denali study area, Alaska).

Plants	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Total Grasses	30.9%	48.3%	39.8%	32.3%	21.3%
Total Sedge/Rushes	37.3%	9.7%	26.5%	35.5%	52.8%
Total Shrubs	17.3%	7.9%	19.9%	15.1%	20.6%
Total Forbs	8.5%	1.3%	10.0%	11.7%	2.4%
Total Mosses	6.0%	23.9%	2.4%	4.0%	2.4%
Total Lichen	0.0%	8.9%	1.4%	1.4%	0.5%
	100.0%	100.0%	100.0%	100.0%	100.0%

Graphs of the 2008 data show a comparison of the original results on a dry-matter basis and on an organic matter basis (ash free) and can be found in appendix 2. Appendix 3 shows a comparison between the 2007 and 2008 results for samples collected on Cathedral Mountain within the Denali study area.

2007-2008 Fecal Analysis Summary

A collaborator on the project, John D. Wehausen, Ph.D., examined and DAPA analysis from the 2007 and 2008 data -collection efforts. His summary analysis follows:

> "The populations sampled were Cathedral Mountain, Chugach Mountains, Sable Mountain, St. Elias Mountains, Wood River, Wrangell Mountains, and Mill Creek Valley.
>
> Only Cathedral Mountain was sampled in both years. I was not provided any information about the sampling sites and have not investigated even their relative locations. The sampling recognized the importance of consistent timing in sampling to make results validly comparable. All sampling took place over a 9 day period (25 July–2 August) and most was within a 6 day period. Consequently, there should be negligible confounding variation due to seasonal variation on plant phenology. The sampling also included replicate samples from each site varying from 2 to 11. With the exception of the sample of only 2 collections from the Chugach Mountains, these were appropriate sample sizes to investigate statistical relationships and variances within samples. Data developed from the samples included not only FN, but also DAPA and total ash. The latter measure allows expression of the results on an organic matter (ash-free) basis, which removes important confounding variation resulting from varying ash contents (Wehausen 1995). This is particularly pronounced where sheep eat dirt at mineral licks and sometimes have a high percentage of ash in their feces. In the current sampling, only one sample showed such high ash levels (St. Elias 5), but another was intermediate (Wrangell Mountains 6). Both would have been statistical outliers on a simple dry matter basis but

were consistent with other samples on an organic matter basis. These data allow some preliminary statistical investigations of temporal and spatial variation. First, the 2007 and 2008 samples from Cathedral Mountain collected within a day of each other are very significantly different for both FN and DAPA (P=0.001) with lower diet quality in 2008. For 2008 the Chugach Mountains were eliminated from analyses due to low sample size. An analysis of variance of the remaining 6 populations exhibited highly significant differences among them (P<0.001) for both FN and DAPA. Removal of outliers identified in these analyses did not change statistical conclusions. Bonferroni post hoc tests of differences found two distinct groups for FN: Cathedral Mountain, Sable Mountain, and Wood River in one group, and St. Elias Mountains, Wrangell Mountains, and Mill Creek Valley in the other, of which the latter showed notably higher diet quality. Locations within each group were very insignificantly different from each other, while each was very significantly different from each location in the other group. Assuming these differences do not reflect a difference in how the samples were collected and processed (I assume all were fresh when collected and dried immediately), these differences would seem to reflect some fundamental habitat differences, like elevation. While DAPA data also exhibited two distinct groups, they were not quite the same; Mill Creek Valley was shifted to the first group, leaving only St. Elias and Wrangell in the second.

I have a great deal of experience with wild sheep FN in a variety of ecosystems. I have also investigated it in great detail using data from domestic sheep and cattle digestion trials (Wehausen 19b95). This extensive experience gives me reason to have considerable faith in FN data from wild sheep as a valid index of diet quality. I have also done some investigations of DAPA which are unpublished. Of concern was the finding of different relationships between DAPA and FN between alpine habitat and low elevation winter range of one bighorn population in the Sierra Nevada. While one cannot rule out the possibility that FN was the inconsistent measure between those 2 ecosystems, my long term experience with FN causes me to lean away from that explanation. Nevertheless, there remains the possibility that plant phenolic compounds in one of the Sierra Nevada ranges caused elevated FN. Relative to the Alaska data set in question, it would be interesting to look for simple covariates that might explain the two groupings for FN and DAPA. While the sampling is limited statistically, a simple covariate like elevation might provide some insight into which of the 2 diet quality measures appears to be the better index (John D. Wehausen, Ph.D., written commun., 2009).

The addition of samples from subsequent years of the study will increase the statistical sampling and also provide opportunities for further investigation into the overall quality of the habitat for wild sheep within our study areas.

Water Analysis

Water samples were collected during 2008 field work and were analyzed by the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. The NWQL performed chemical analysis on water samples to determine organic and inorganic constituents.

Samples were collected in both the Wood River (July 29-30, 2008) and Denali (August 1-2, 2008) study areas. The two samples taken at Wood River were collected from a running stream. At the Denali study site, two samples were taken from glacial streams and two from springs that were the result of permafrost melt.

Overall, water-analysis results showed low nutrient values at all sites. This is most likely due to the samples being taken from locations where the water was not mixed with soils long enough to pick up nutrients. Rainwater runoff or water previously frozen in permafrost or glaciers and recently released would not have had the chance to absorb nutrients. Typically, water samples from ponds or lakes have the highest levels of nutrients, because the water has had time to mix with soils and leafy material and absorb their nutrients. Samples were analyzed for:

- nitrogen, nitrite + nitrate
- nitrogen, ammonia as N
- nitrogen, nitrite
- ortho-po4 (phosphorus, phosphate, ortho)

Details about each water sample are shown in table 2, and the actual water sample analyses results are shown in table 3.

Table 2. Water samples collected during 2008 field work, Alaska.

Sample #	Location	Date	Time	Coordinates	Water Temperature (F)	Elevation (feet)	Collection Description	Site Description
1	Wood River	7/29/2008	12:41pm	N 63 degrees 44.218 W 147 degrees 38.850	38 degrees	3950	35 ml, filtered through 22 micron filter	Running stream into small pool, surrounded by willows; On the edge/side of the Wood River
2	Wood River	7/30/2008	10:47am	N 63 degrees 44.218 W 147 degrees 38.850	40 degrees	3950	dipped/not filtered	same as sample #1, only dipped
3	Denali -- Cathedral Mtn.	8/1/2008	11:00am	N 63 degrees 34.390 W 149 degrees 37.757	45 degrees	3329	250 ml filtered through 22 micron filter	glacial stream
4	Denali -- Sable Mtn.	8/1/2008	3:30pm	N 63 degrees 33.913 W 149 degrees 39.974	44 degrees	3768	250 ml filtered through 22 micron filter	glacial stream
5	Denali --- Cathedral Mtn.	8/2/2008	12:08pm	N 63 degrees 35.545 W 149 degrees 36.349	50 degrees	3471	250 ml filtered through 22 micron filter	spring -- permafrost melt
6	Denali -- Sable Mtn.	8/2/2008	12:30pm	N 63 degrees 35.517 W 149 degrees 36.495	48 degrees	3378	250 ml filtered through 22 micron filter	spring -- permafrost melt

Table 3. Chemical-analysis results for water samples collected during 2008 field work.

Sample 1:			
Parameter	**Result**	**Units**	**Final Result**
nitrite + nitrate (no2+no3), as n, filtered	0.057	mg/L	0.057
ammonia, kone	0.00666	mg/L	<0.02
nitrite, kone	0.00356	mg/L	0.004
ortho-po4, kone	0.00602	mg/L	0.006
Sample 2:			
Parameter	**Result**	**Units**	**Final Result**
nitrite + nitrate (no2+no3), as n, filtered	0.04	mg/L	0.04
ammonia, kone	0.00417	mg/L	<0.02
nitrite, kone	0.00182	mg/L	E0.002
ortho-po4, kone	0.00558	mg/L	E0.006
Sample 3:			
Parameter	**Result**	**Units**	**Final Result**
nitrite + nitrate (no2+no3), as n, filtered	0.222	mg/L	0.222
ammonia, kone	0.00468	mg/L	<0.02
nitrite, kone	0.00056	mg/L	<0.002
ortho-po4, kone	0.00793	mg/L	0.008
Sample 4:			
Parameter	**Result**	**Units**	**Final Result**
nitrite + nitrate (no2+no3), as n, filtered	0.175	mg/L	0.175
ammonia, kone	0.00129	mg/L	<0.02
nitrite, kone	0.0004	mg/L	<0.002
ortho-po4, kone	0.00645	mg/L	0.006
Sample 5:			
Parameter	**Result**	**Units**	**Final Result**
nitrite + nitrate (no2+no3), as n, filtered	0.053	mg/L	0.053
ammonia, kone	0.0001	mg/L	<0.02
nitrite, kone	0.00094	mg/L	<0.002
ortho-po4, kone	0.00465	mg/L	E0.005
Sample 6:			
Parameter	**Result**	**Units**	**Final Result**
nitrite + nitrate (no2+no3), as n, filtered	0.027	mg/L	E0.027
ammonia, kone	0.00202	mg/L	<0.02
nitrite, kone	0.0004	mg/L	<0.002
ortho-po4, kone	0.00646	mg/L	0.006

Robert J. Hart (USGS, Arizona Water Science Center) gave the following summary of the water analysis results:

> Low concentrations (less than 0.25 mg/L) of nitrogen—nitrate and nitrites—were observed in surface-water and spring samples from the Wood River Basin and Denali National Park, Alaska, during the summer of 2008. Concentrations of nitrate plus nitrite in selected surface water and spring sites ranged from 0.027 to 0.222 mg/L. Samples analyzed from surface-water sites (glacial outwash) showed the highest concentrations and ranged from 0.175 to 0.222 mg/L. Samples with the lowest values (less than 0.060 mg/L) were observed at springs which discharge from the

permafrost soils. Nitrite concentrations comprise only a small portion of the nitrate plus nitrite and ranged from 0.0004 mg/L to 0.0035 mg/L. National background concentrations of nitrate are 0.6 mg/L or less for streams, and 2.0 mg/L or less for shallow ground water (U. S. Geological Survey Circular 1225). Other nutrients, including ammonia, were less than 0.02 mg/L and ortho-phosphate ranged from 0.006 to 0.008 mg/L. The low concentrations of nitrogen observed at the Denali sites are probably due to the nature of the permafrost soils, which are near the surface, cold, poorly drained, and typically low in nitrogen. Likely sources of nitrogen include atmospheric deposition and waste from wildlife that live in the watershed. Concentrations of nitrogen in water are likely controlled by meltwater and runoff, minerals in the permafrost soils, and biological activity that occurs. (Robert J. Hart, written commun., 2009).

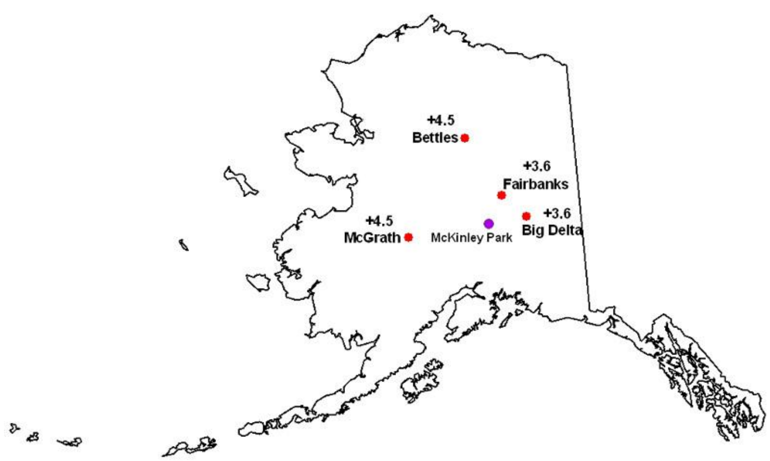
Climate Data

"Climate appears to regulate sheep population density and is probably the ultimate determinant of sheep quality through mechanisms which are not understood" (Heimer and Smith, 1975, p. 21). The intent of this project is to determine whether climatic changes are altering the traditional habitat for wild sheep, therefore we must take into account statistical information on the climate change that is occurring. Several programs administered by various Federal agencies and private entities either deploy and/or manage weather stations throughout Alaska, and much of this data is archived by the Alaska Climate Research Center.

To ascertain temperature and precipitation trends, we used climate data from National Weather Service (NWS) first-order observing stations, which are professionally maintained by the NWS or the Federal Aviation Administration. Data was downloaded from the National Climatic Data Center. We chose to concentrate on first-order stations located in the interior region of Alaska because of their proximity to our study areas. There are no first-order stations close to our study sites that have comparable elevations. The stations used were Bettles (641.9 ft), Big Delta (1267.7 ft), Fairbanks (435.9 ft), and McGrath (332.9 ft).

Using data from 1953 to 2007, a linear trend was taken through mean annual temperatures of the four stations. The temperature change during the 55-year period averaged +4.1 (degrees Fahrenheit) for all four stations combined (fig. 15).

Figure 15. Total change in mean annual temperature (degrees Fahrenheit), 1953–2007 at four first order stations close to our study sites. The location of the McKinley Park station also is shown.



However, looking at just the total linear trend masks the variability over time. Figure 16 shows mean annual temperature departure for the same four interior stations during the same time period, graphed by years. The trend is nonlinear. The Alaska Climate Research Center attributes the shift in temperature that occurred in 1976 to a phase shift of the Pacific Decadal Oscillation from a negative to positive, resulting in increased southerly flow and warm air advection into Alaska during the winter (Alaska Climate Research Center, 2008). Heimer and others (1994) have advanced this hypothesis for more than a decade. This is corroborated in figure 15, which shows the total change in mean seasonal and annual temperature from 1953 to 2007 broken down by seasons. Using monthly summary data, prior year December data was included with following year January and February data for winter statistics. March, April, and May data were used for spring; June, July, and August data for summer; and September, October, and November data were used for autumn. For these four interior stations, most of the change took place in winter, followed by spring. The annual totals for Bettles, Big Delta, and Fairbanks differ by one-tenth of a percent from the yearly totals shown on the Alaska map (fig. 17), most likely because of differing December data used for the separate calculations.

Figure 16. Mean annual temperature departure for four first order stations, 1953–2007.

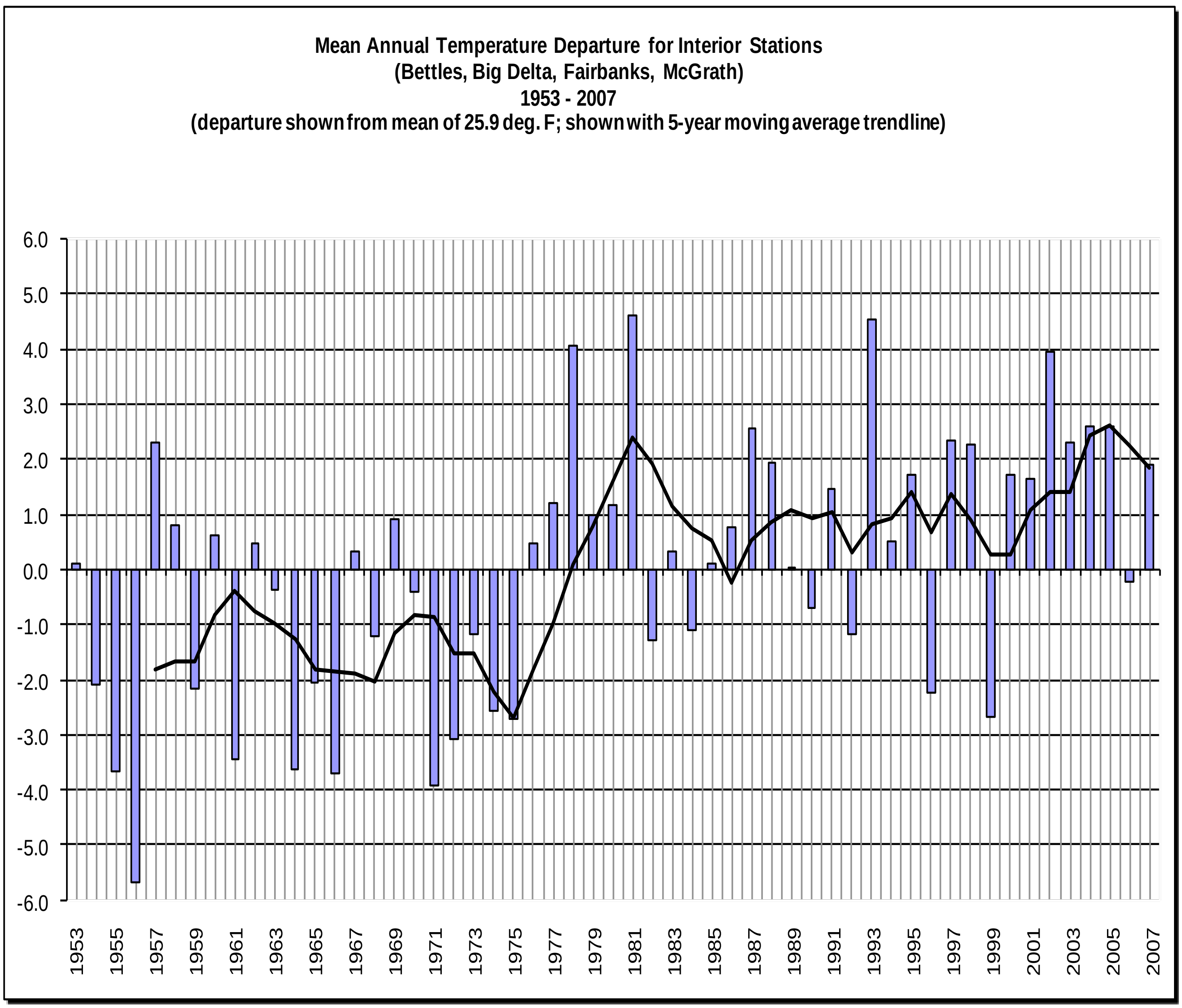
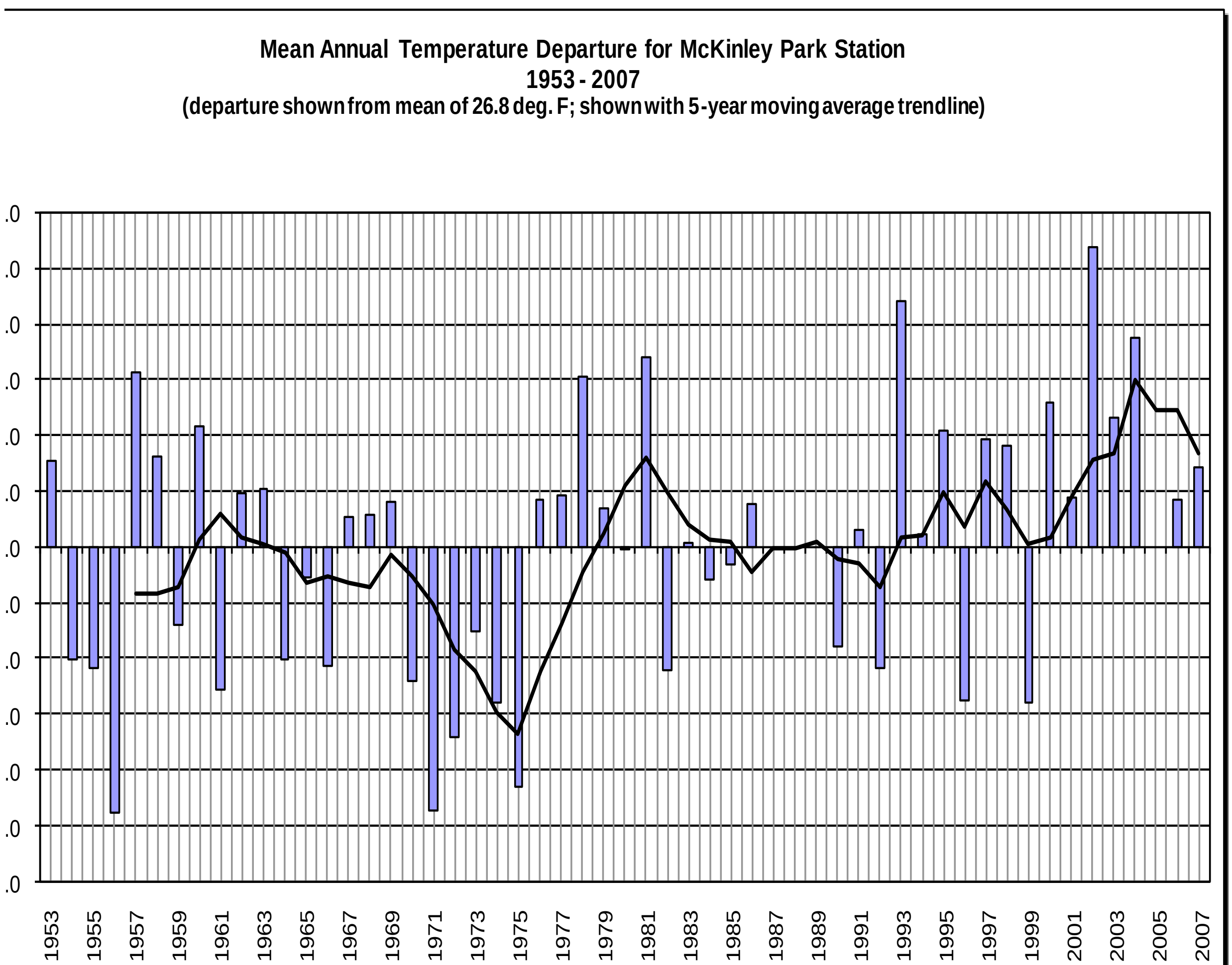


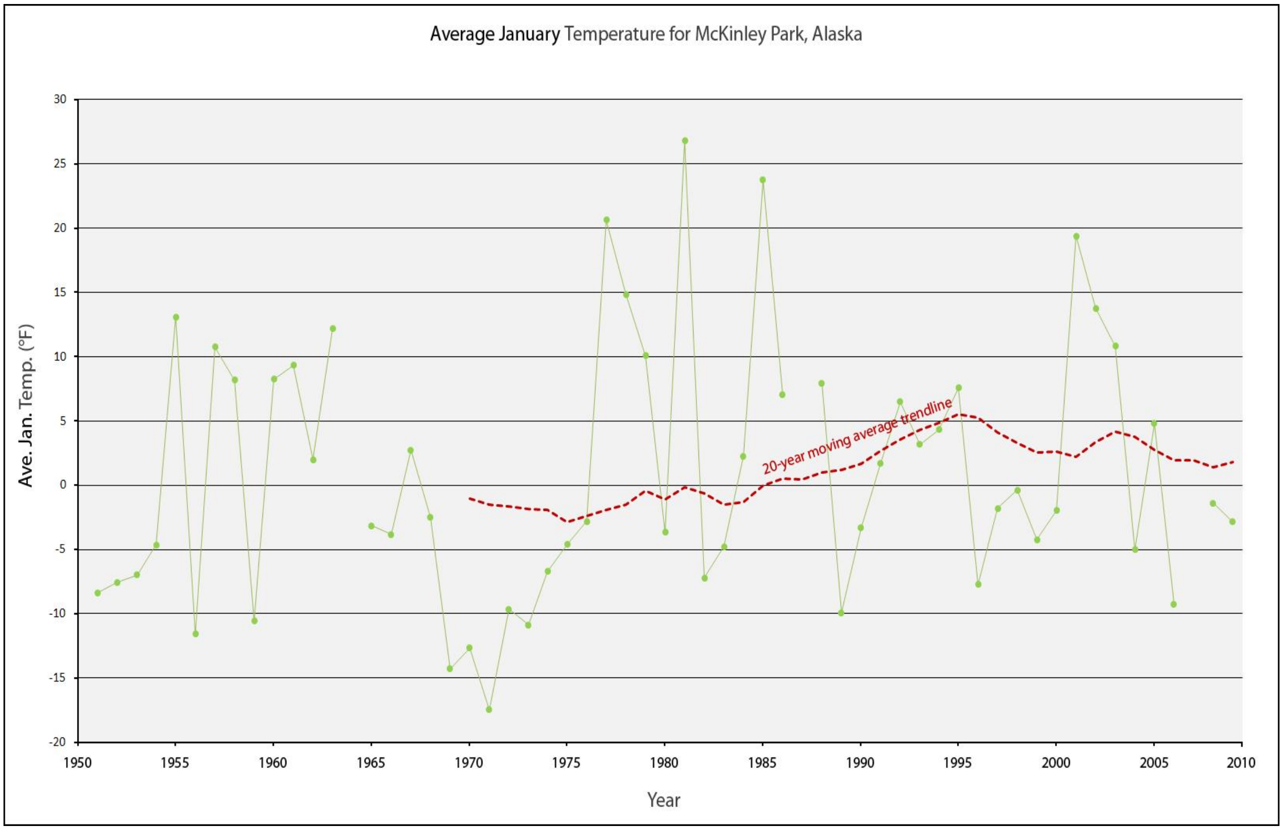
Figure 17. Total change in mean annual temperature (degrees Fahrenheit) 1953–2007, by season.

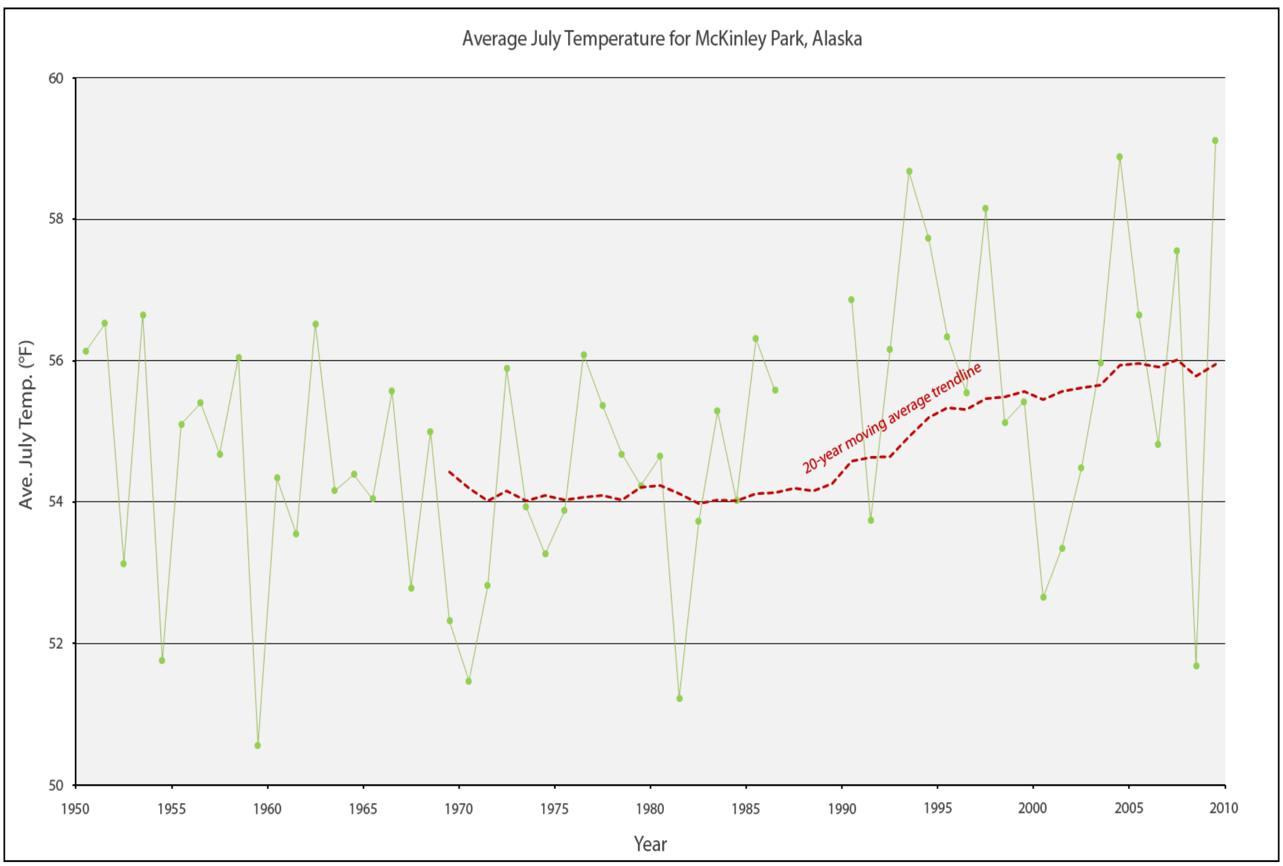
Location	Winter	Spring	Summer	Autumn	Annual
Bettles	8.8	4.4	2.0	2.6	4.4
Big Delta	8.5	3.5	1.3	1.3	3.7
Fairbanks	7.2	3.8	2.0	1.2	3.5
McGrath	7.0	4.8	3.0	3.0	4.5

Data nearer our Denali study area were available from the McKinley Park station, part of the U.S. Cooperative Observing Network. This station has a higher elevation (2,070 ft) than the four stations mentioned above, but was not as complete a dataset. Four years were not included owing to too many months of missing data. With that in mind, the McKinley Park station had a mean temperature change linear trend of 2.8% and a mean of 26.8 (degrees Fahrenheit) from 1953 to 2007. Compared to the four first order stations referenced above, the mean temperature change linear trend was less (by 1.3%), and the mean temperature was slightly warmer (by 0.9 degrees Fahrenheit). When we look at a graph of the mean annual temperature departure, the trend of the 5-year moving average is similar to that of the other interior stations, except that it seems to indicate less deviation from the mean for most years during this time period (fig. 18).

Figure 18. Mean annual temperature departure for McKinley Park Station, 1953–2007.




Average January Temperature for McKinley Park, Alaska
Ave. Jan. Temp. (°F)
30
25
20
15
10
5
0
-5
-10
-15
-20
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
20-year moving average trendline


Average July Temperature for McKinley Park, Alaska
Ave. July Temp. (°F)
60
58
56
54
52
50
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
20-year moving average trendline

Additional research will be done on data from the McKinley Park station to examine potential vegetation phenology changes and their relationship with broader-scale patterns of landscape phenology observed in the remotely sensed satellite data.

The Central Alaska Network (CAKN), part of the National Park Service Inventory and Monitoring Program (NPS I&M), monitors weather stations located in or near three national park units in Alaska and also has data pertinent to our study areas. Climate data inventories for the NPS I&M Program are maintained by and accessible through the Western Regional Climate Center. Two of these stations were close to our Denali study area, the Toklat and Dunkle Hills stations. The Toklat station is at an elevation of 890 ft and only has annual data available for 2006, 2007, and 2008. Dunkle Hills is at an elevation of 808 ft and has annual data available for 2005-2008. For the limited annual data available, Toklat had a mean annual air temperature of 25.7 (degrees Fahrenheit), and Dunkle Hills 27.7 (deg F). This is comparable to the historical annual temperature mean of 26.8 (deg F) for the McKinley Park station from 1953 to 2007. Although there is not enough historical data from these stations to derive trends, they can provide indications of the weather at our Denali study site and provide comparisons to future McKinley Park station data.

Precipitation trends also were calculated for the four first-order observing stations used for our temperature trends. By using precipitation data from 1953 to 2007, a linear trend was taken through the average yearly precipitation levels of these four stations. The change in annual precipitation based on the linear trends for each station showed an average increase of 1.4 inches during the study period. Changes in the individual station amounts are shown in figure 19 and indicate that Bettles and McGrath stations had an increasing trend in precipitation, while the Fairbanks and Big Delta stations had a small decreasing trend. Figure 20 shows mean annual precipitation departure for the four interior stations during the same time period, graphed by years. The trend is non linear and shows variable departures from the average precipitation over time.

Additional research of climate variables associated with our study areas will be investigated as possible input into predictive-model development of expected climate-driven wild sheep habitat changes.

Figure 19. Total change in average annual precipitation (inches), 1953–2007 at four first-order stations close to our study sites.

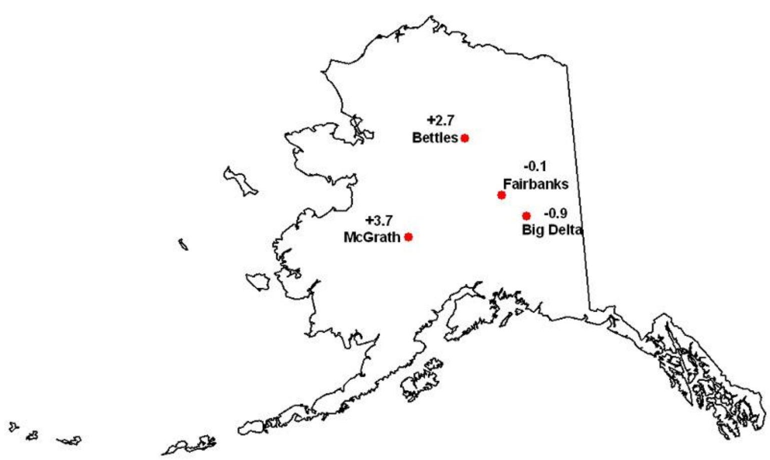
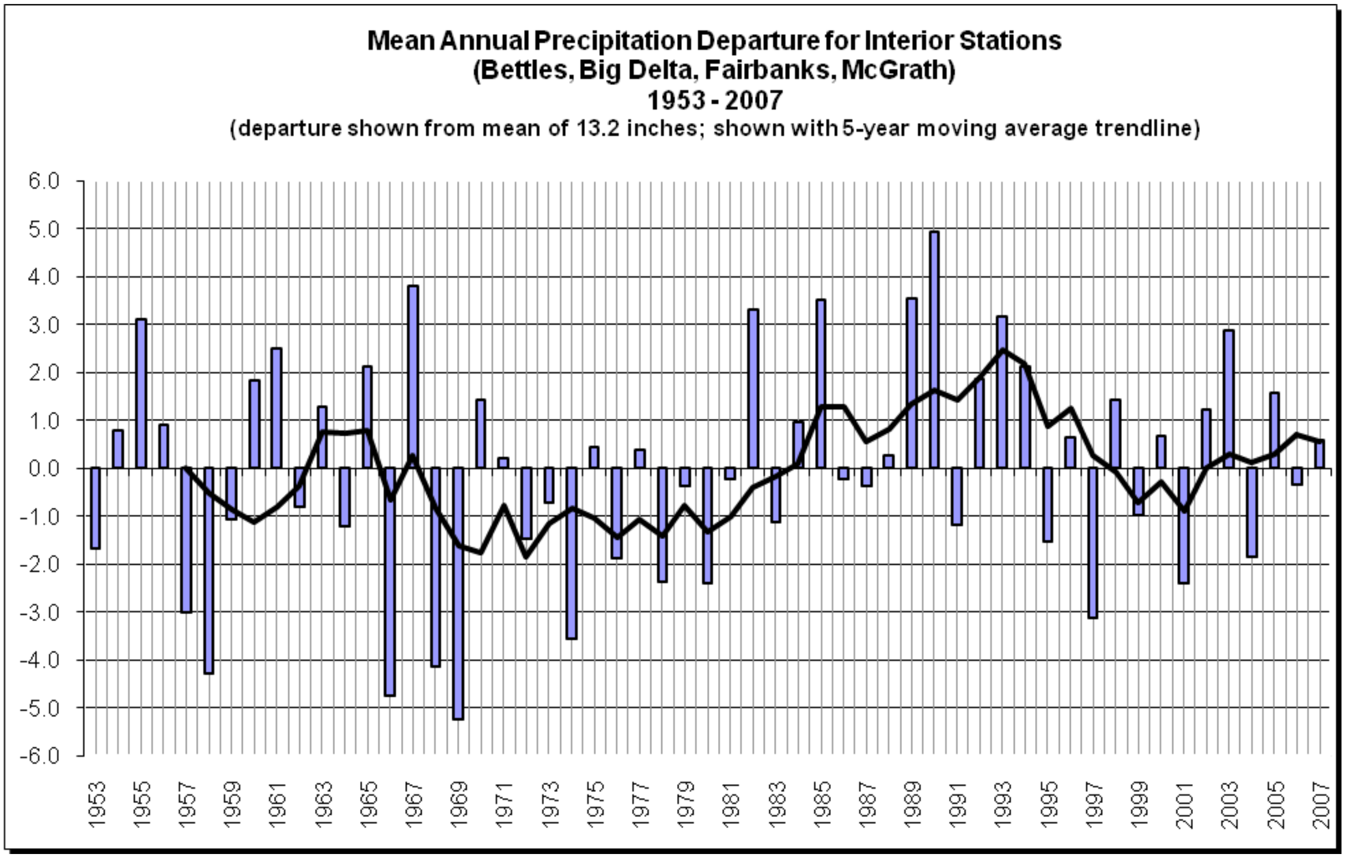


Figure 20. Mean annual precipitation departure for four first-order stations, 1953–2007.



Vegetation Mapping

Denali Vegetation Mapping

As part of the effort to collect ground-based observations pertinent to overall wild sheep habitat, GPS points were collected along shrub community boundaries and within vegetation types to aid in developing coarse vegetation maps of our study areas. A polygon of GPS points was acquired around two shrub communities on the north-facing slope of Cathedral Mountain. Shrub areas were dominantly willow (Salix spp.) and alder (fig. 21). More of these shrub perimeter polygons will be delineated in future field work to gather localized information on the suspected up-slope encroachment of woody plants. These polygons also will be used to map generalized vegetation types, such as woody and nonwoody vegetation, from Landsat and Quickbird satellite imagery. In addition, high resolution Quickbird imagery will allow accurate polygons to be delineated and used in supervised classification of Landsat data. This Landsat image classification will allow monitoring of woody/nonwoody plant distribution and possible upslope movement over larger areas and several decades.

Figure 21. Shrub community in the Denali National Park study area.

Plants from sheep fecal sample locations were collected and identified. These plants also were listed as part of the sheep's diet in the detailed diet composition analysis (Appendix 1) from feces (pellets) collected in 2007. Some of the plants are identified below.

Grasses:
Gramineae/Poaceae (grass family)
Arctagrostis latifolia (common name: polargrass)
Fesstuca spp (common name: fescue)
Poa spp. (common name alpine bluegrass

Sedges/Rushes:
Carex spp. (common name : sedge)
Juncus spp. (common name: Rushes)

Shrubs:
Arctostaphtlos (common name: bearberry)
Betula (common name: birch)
Cassiope tetragona (common name: white arctic mountain heather)
Empetrum nigrum (common name: black crowberry)
Salix (common name: willow)
Leguminosae/Fabaceae (Common Name: Pea)
Caespitosa (Common Name: Evening Primrose)
latifolium (common names: dwarf fireweed, river beauty)
Vaccinium uliginosum (common name: Bog Blueberry)

Forbs:
Epilobium (common name: river beauty)
Equisetum (common name: horsetail)
Geum spp (common name: Avens)

Mosses:
Lycopodiaceae (common name: club moss)
Polytrichum (common name: haircap moss)

Pea:
Fabaceae (Common name: Pea)
Hedysarum alpinum (common name: alpine sweetvetch)

Rose:
Dryas octopetala, spp: (common name: mountain avens)
Geum Rossii (common name: Ross' avens)

Willow:
Salix reticulata (common names: netleaf or netted willow)
Salix arctica (common name: arctic willow)
Heath:
Cassiope tetragona (common name: white arctic mountain heather)
Vaccinium uliginosum (common names: bog or alpine blueberry)

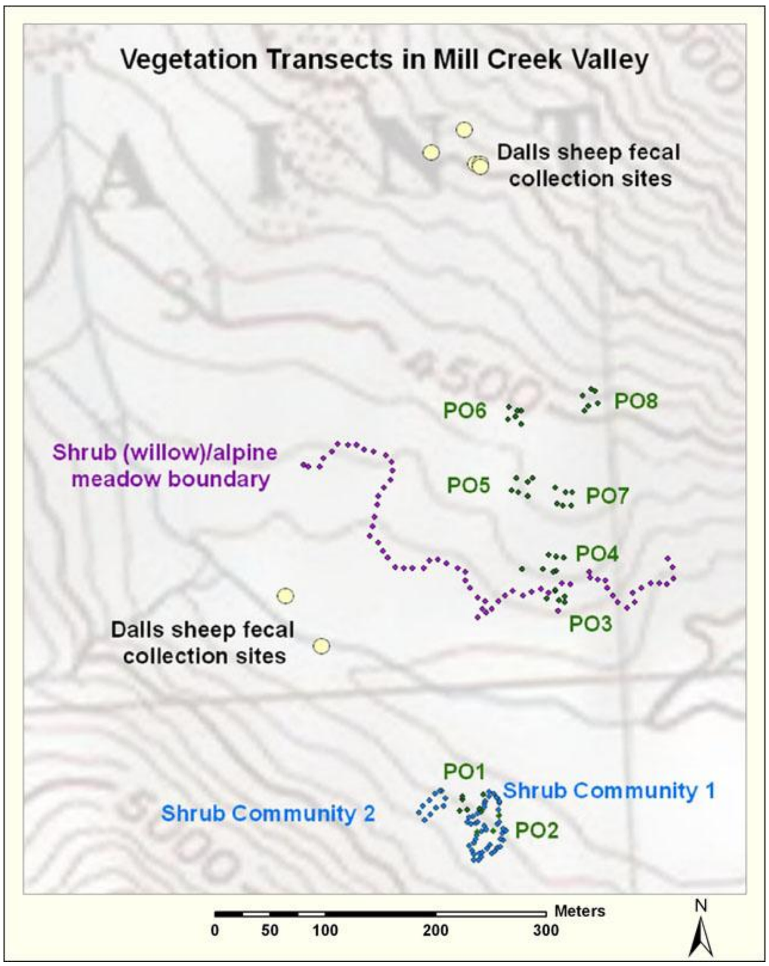
Mill Creek Valley Vegetation Mapping

The following vegetation information was collected and documented by students in the Alaska Wildlands Program at the Wrangell Mountains Center, under the direction of Dr. Megan K. Gahl (Director, Alaska Wildlands Studies Program). The students described a set of alpine vegetation communities, identified on the map as PO1…PO8. Each of the eight plots (30 by 30m) were oriented true North/South with a North/South transect through the middle. Figure 22 shows locations of vegetation information and Dall's sheep fecal samples collected for this project. In each plot the students:

- Identified the dominant community type, based on the highest canopy level that covered 30% of the plot. These community types were categorized as tree, shrub (10 cm to 3 m), low-lying shrub (<10 cm with a woody stem) or herbaceous.
- Identified the three most abundant species within each canopy level.
- Further documented the presence/absence of nondominants and quantified relative abundance of plants within each community by performing transect/quadrant analysis (3 quadrants (1 x 1m) at the 0m, 10m, and 20m marks along the transect).

Details of the vegetation types found in each of the plots/quadrats can be found in Appendix 4.

Figure 22. Location of vegetation transects in Mill Creek Valley and their relationship to Dall's sheep fecal collection sites.



The students also delineated an alpine shrub/meadow boundary on the north slope by taking GPS points every 20m, using >50% shrub as the general dividing line for community type. Two shrub communities on the south slope were delineated by taking GPS waypoints every 10 or 20 meters around two large willow islands within the alpine meadow.

The students' final report, ***Dall sheep in the Upper Mill Creek Valley: An analysis of vegetation composition and range in Ovis dalli dalli habitat*** can be found in Appendix 5. The complete report contains additional discussion on their vegetation mapping and Dall's sheep scat collection methodologies and results, and provides valuable insight into wild sheep habitat. A portion of their summary follows:

Vegetation Boundaries

Shrub areas were dominantly willow, *Salix spp*., throughout the upper valley. The north-facing slope was predominantly alpine vegetation such as low-lying shrubs less than 10cm tall. The 2 outliers were willow islands at mean elevations of 470m and 220m respectively. The south-facing slope had a well-defined shrub/alpine meadow boundary at a mean elevation of 1,280 m. The shrub-zone was confined laterally by a glacial moraine to the west and a limestone rockslide to the east. The valley floor surrounding the creek contained primarily willow on both sides at a mean elevation of 1,235m.

Vegetative Community Survey

Of the plots on the north-facing slope, 1 was herbaceous, 1 was shrub. On the south-facing slope 1 was herbaceous, 4 were shrub, and 1 plot was unvegetated limestone (rockslide scree <=1m). Both of the single quadrats were herbaceous communities. We identified 45 individual plant species within the 8 plots and 2 individual quadrats. Of the 45 species, 7 were found exclusively in plots where scat was present, 25 were found exclusively in plots where scat was not present, and the remaining 13 were found in plots both with and without scat.

The average richness within each plot was 14 species with a minimum of 12 and maximum of 16. While the average richness was similar among all plots, scat-present plots had an overall lower diversity because of reoccurring plant species such as *Salix reticulata* and *Dryas octopetela*. In general, the north-facing slope was less diverse than the south-facing slope (Connor 2008).

Discussion

We found that sheep scat was not evenly distributed among vegetation communities in the upper Mill Creek Valley. Higher abundance of sheep scat was strongly correlated with higher elevation. This is consistent with previous research observations that sheep inhabit steep slopes at higher elevations (Geist, 1971).

Plant diversity was low in scat-present plots relative to non-scat plots. Scat-present plant species were dominantly low-lying shrubs, particularly *D. octopetala* and *S. reticulata*. Because sheep are known to be specific grazers (Geist, 1971), this correlation could explain why particular plant species (i.e., food sources) were reoccurring. Although scat was not found on the north-facing slope, characteristic of relatively low plant diversity, the presence of previous season's scat suggest that sheep may use this slope as vegetation accessibility changes throughout the year" (Chatterson and others, 2008).

Summary and Future Research Direction

Project efforts to date have focused on collecting data on a suite of factors that could contribute information about the effects that glacial melting and snowfield retreat are having on wild sheep habitat in selected areas of Alaska. Among these factors are long-term weather effects on glacial extent and change, nutrient content of water, nutritional quality of forage (through fecal analysis), and vegetation type and change. The project has thus far been an exploratory investigation to identify physical variables that are most informative about wild sheep habitat change in the study areas. For some variables, in addition to collecting contemporary data, historical datasets exist that are being compiled and leveraged.

For other variables, such as the fecal analyses, no prior data existed, and this study established baseline datasets. Through this initial research, several findings have become apparent:

- The surface area of glaciers and permanent snowfields along a selected portion of the Alaska Range in Denali National Park experienced an estimated 47-percent decline from 1979 to 2007. The mean elevation of these glaciers and permanent snowfields also increased by an estimated 40.5 meters (133 ft). The ablation zones of the mapped glaciers diminished by an estimated 57 percent while the accumulation zone declined approximately 41 percent during this same period.
- Available climate data indicates a linear warming trend at stations near our study areas, with nearby stations averaging an increase of 4.1 (degrees Fahrenheit) from 1953 to 2007. A shift toward warmer temperatures seems to have occurred in 1976, concurrent with changes in the Pacific Decadal Oscillation. The greatest proportion of the increase in mean annual temperature seems to be occurring during the winter months. Precipitation trends for this same time period were less revealing, with two stations indicating an increase in precipitation and two stations having a decrease, resulting in an overall estimated increase in average yearly precipitation of 1.4 in.
- Results of the Dall's sheep fecal analysis show low-to mid-level nutrient levels in the forage collected at the Denali study sites. Nutrient levels in the forage collected in the Wrangell Mountains appear to be higher than at Denali. The 2007 and 2008 Cathedral Mountain samples from the Denali study site showed significant yearly differences in FN and DAPA, with 2008 results showing lower diet-quality estimates. The 2008 samples from other sites varied significantly in their DAPA and FN values. Further research will be done to try and correlate these and subsequent years of fecal-analysis data with other factors that might explain their variability.
- Fecal analysis for FN, DAPA, and diet composition, along with vegetation transects, have confirmed the dominant and preferred vegetation of the wild sheep habitat within the study areas. Additional analysis of vegetation distribution using remotely sensed data and supplemental vegetation transects needs to be done to determine the extent of upslope movement of woody plants into traditional Dall's sheep forage areas.
- Water-analysis results showed consistently low nutrient levels from all collection sites within the study areas, and probably will not provide useful information with regard to evaluating changes occurring within the wild sheep habitat; however, samples will continue to be collected to monitor any potential changes.

The documented melting of glacial ice, snowpack, and perhaps permafrost is probably because of generally increased air temperature and is likely to have an impact on forage available to Dall's sheep. The increased influx of water during the growing season may lead to increased growth and higher nutrient levels in the forage. However, should this trend continue, the process may eventually result in reduced water availability to the habitat as snow cover, glacial ice , and permafrost ultimately become depleted. Analysis of phenological changes in vegetation and additional change detection research, in conjunction with the climate data, fecal-analysis results, and other ancillary datasets, could provide a foundation to support these hypotheses.

Future research tasks include continued collection of Dall's sheep feces and water samples for analysis of nutrient levels at Denali and other locations in Alaska. Further analysis of glacial melting also will be initiated by using 1950s aerial photography to determine the extent of glacial ice and permanent snow fields during that period. Various products will be generated using Landsat and MODIS imagery to evaluate phenological changes in the vegetation regime over time. Additional vegetation transects will be taken during field work and utilized in conjunction with historical and remotely-sensed data to determine the extent of upslope migration of woody plants.

Finally, all of our collected data will be utilized in the future for development of models to evaluate changes in sheep habitat extent and quality that we document have taken place historically and these models will be used to predict the future habitat under likely climate change scenarios. Such predictive models will provide a valuable tool to evaluate anticipated changes in the Dall's sheep habitat, thereby informing management actions to sustain and increase sheep populations, enhance sheep health, and preserve economies that depend on the presence of wild sheep herds.

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Appendices

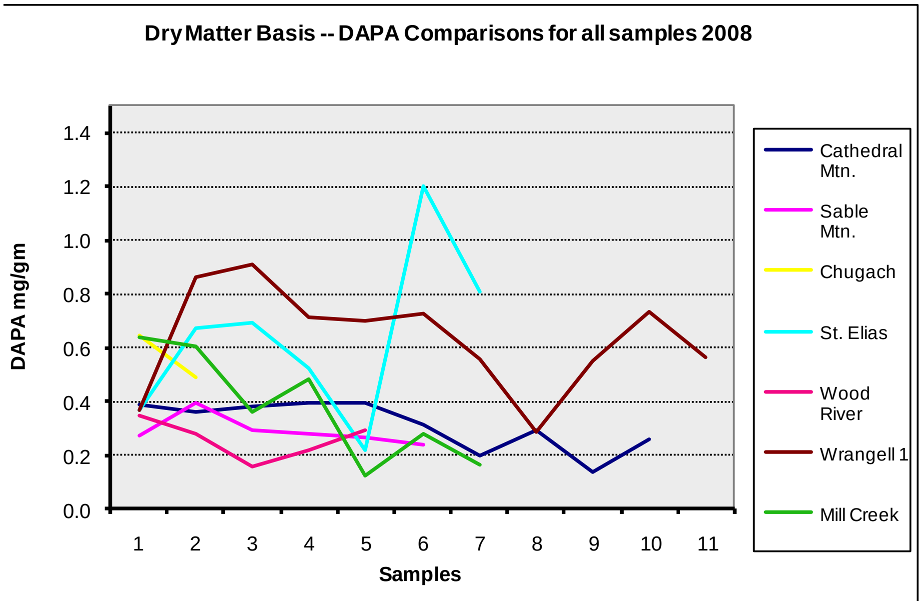
Appendix 1. Detailed diet composition analysis prepared by the Wildlife Habitat Laboratory at Washington State University, from 2007 wild sheep fecal samples collected on Cathedral Mountain in Denali National Park.

Pfeifer
Sheep
Cathedral Mtn.
Flagstaff, AZ

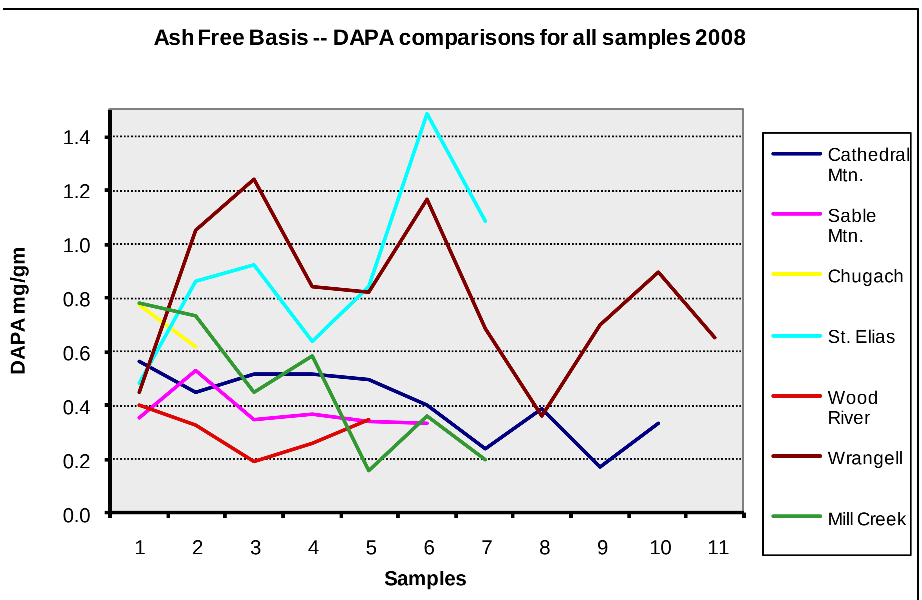
Plants	#1	#3	#4	#5	#6
Arctagrostis latifolia	6.3	2.5	7.6	7.6	7.0
Festuca spp.	5.3	8.1	6.0	3.4	1.8
Poa spp.	18.0	35.9	23.6	18.6	11.1
Unknown Grasses	1.3	1.8	2.6	2.7	1.4
Total Grasses:	30.9 %	48.3 %	39.8 %	32.3 %	21.3 %
Carex spp.	29.3	4.6	20.1	24.9	38.1
Juncus spp.	8.0	5.1	6.4	10.6	14.7
Total Sedge/Rushes:	37.3 %	9.7 %	26.5 %	35.5 %	52.8 %
Arctostaphylos		0.8			
Betula stem		0.5			
Cassiope tetragona leaf		0.5			
Dryas octopetala leaf	7.5	2.8	11.6	8.1	7.4
Dryas octopetala stem		0.5			
Empetrum nigrum leaf		0.8			
Salix leaf	4.1		6.1	6.8	9.0
Salix stem	4.3		2.2	0.2	4.2
Vaccinium uliginosum stem		1.5			
Shrub leaf	0.7				
Shrub stem	0.7	0.5			
Total Shrubs:	17.3 %	7.9 %	19.9 %	15.1 %	20.6 %
Epilobium latifolium	0.3		1.4	4.0	0.5
Equisetum	0.7	1.3	0.7	3.4	
Geum spp.	0.7		0.5	0.5	
Hedysarum alpinum	6.1		6.2	2.0	0.3
Unknown Forbs	0.7		1.2	1.8	1.6
Total Forbs:	8.5 %	1.3 %	10.0 %	11.7 %	2.4 %
Aulacomnium Moss	1.0	1.3		1.1	
Classic Moss	5.0	20.3	2.4	2.9	2.4
Polytrichum Moss		2.3			
	6.0 %	23.9 %	2.4 %	4.0 %	2.4 %
Lichen	0.0 %	8.9 %	1.4 %	1.4 %	0.5 %
TOTAL	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %

Appendix 2. Graphs of fecal analysis results for all 2008 samples. Graphs for DAPA and FN are shown for the original results which have not been compensated for the ash content (dry-matter basis), and also after the ash has been compensated for (organic-matter basis, or ash-free basis).

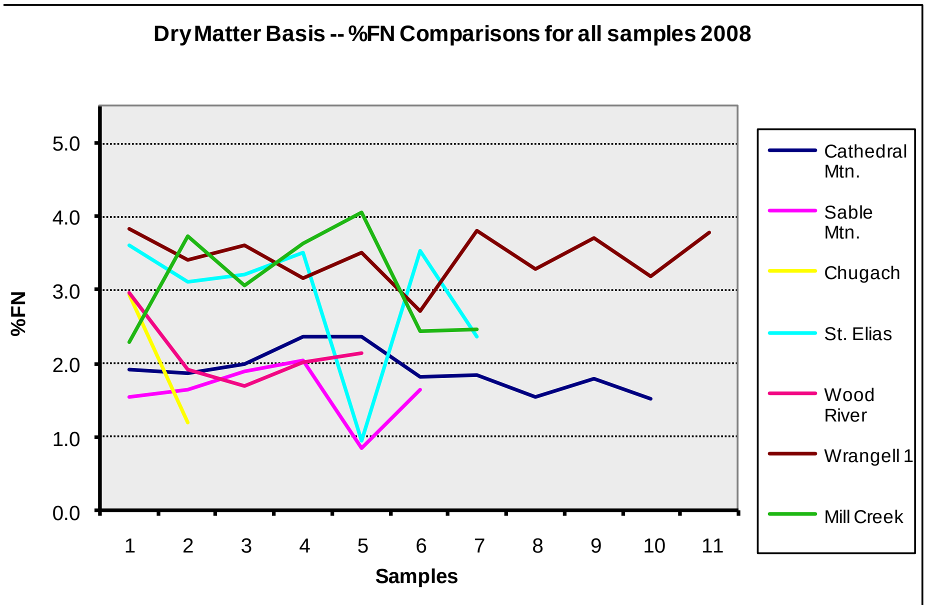
2.1 DAPA comparisons of all 2008 samples (dry matter basis).



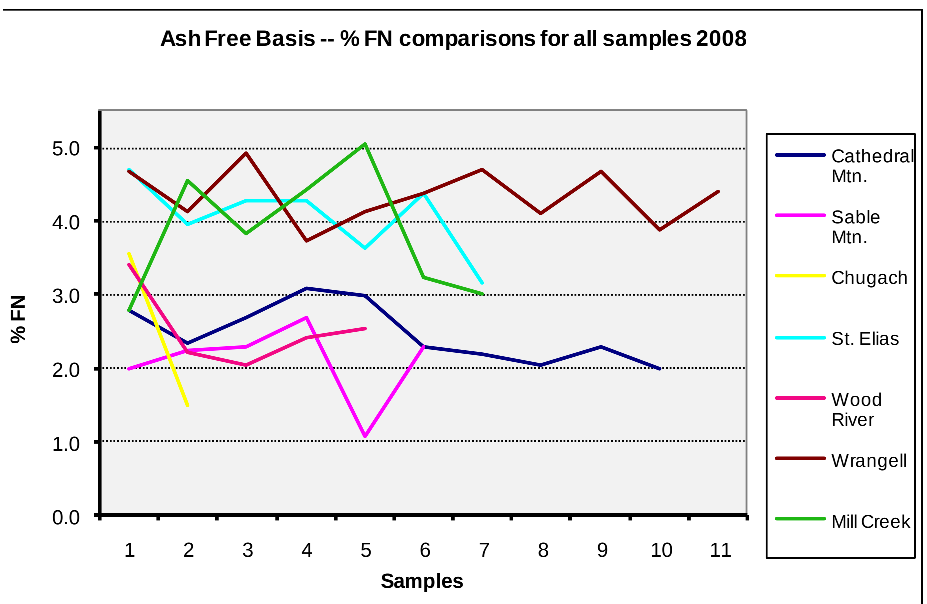
2.2 DAPA comparisons of all 2008 samples (ash free basis).



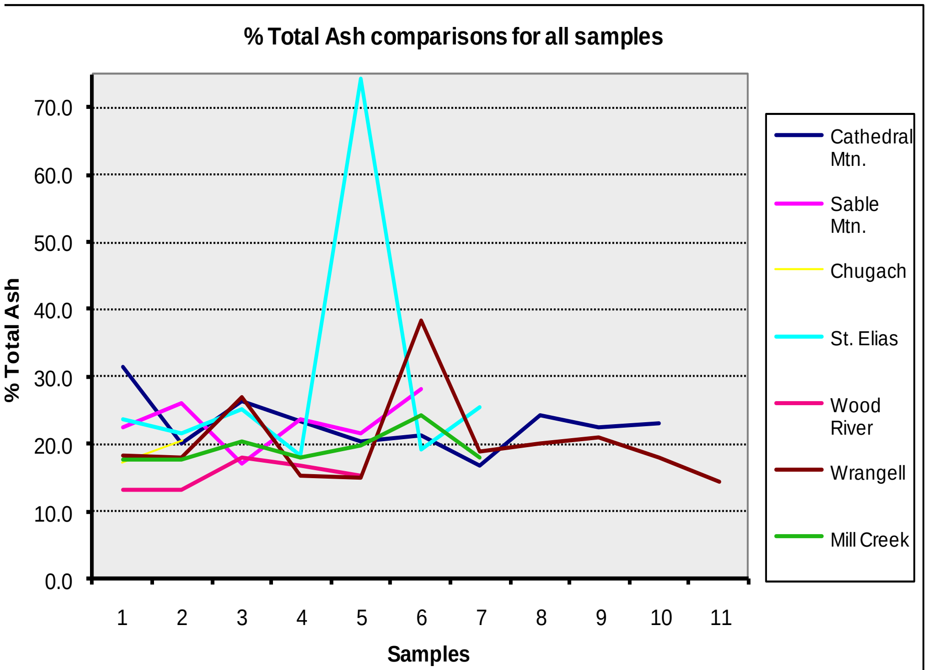
2.3 Percent FN comparisons of all 2008 samples (dry matter basis).



2.4 Percent FN comparisons of all 2008 samples (ash free basis).

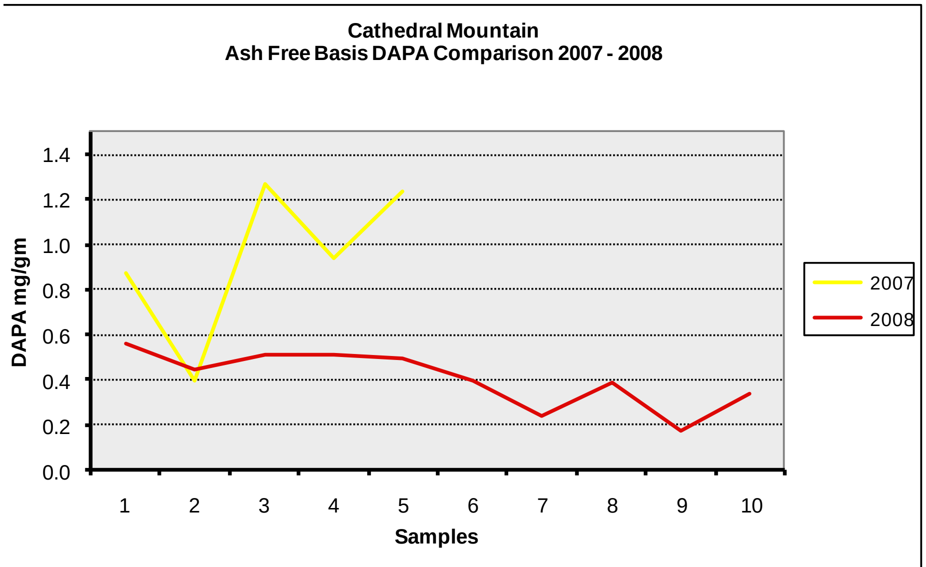


2.5 Percentage of total ash for all 2008 samples.

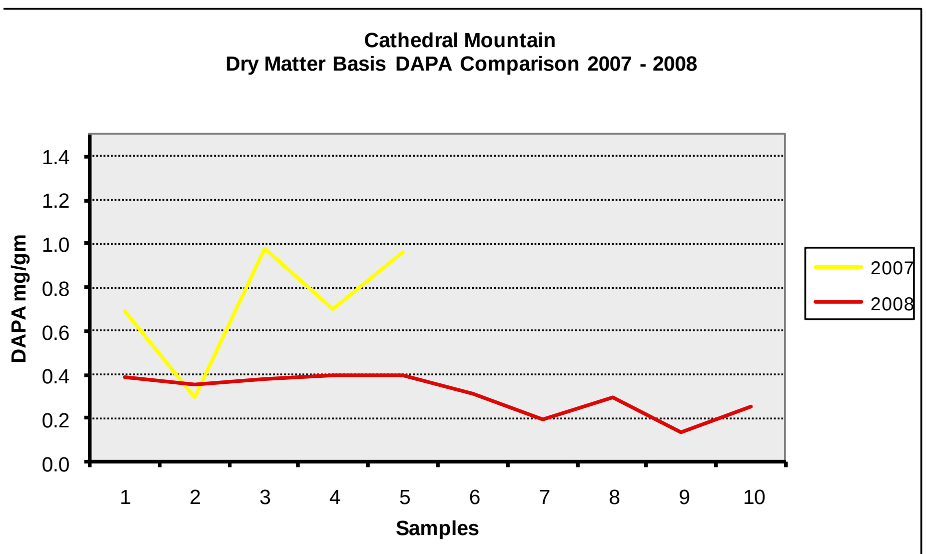


Appendix 3. Comparisons of fecal analysis results between the 2007 and 2008 samples collected on Cathedral Mountain, in Denali National Park, Alaska. Graphs for DAPA and FN are shown for the original results which have not been compensated for the ash content (dry matter basis), and also after the ash has been compensated for (organic matter basis, or ash free basis).

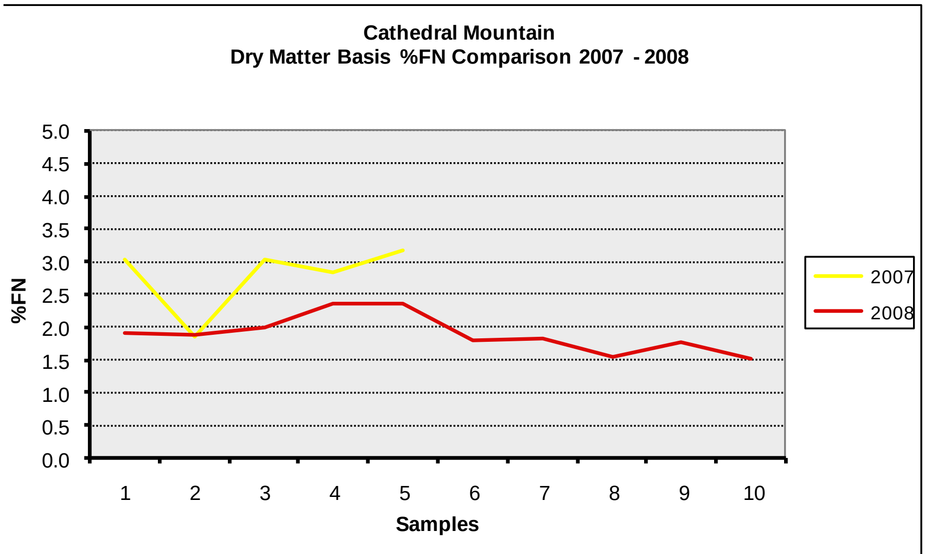
3.1 DAPA comparisons (dry-matter basis).



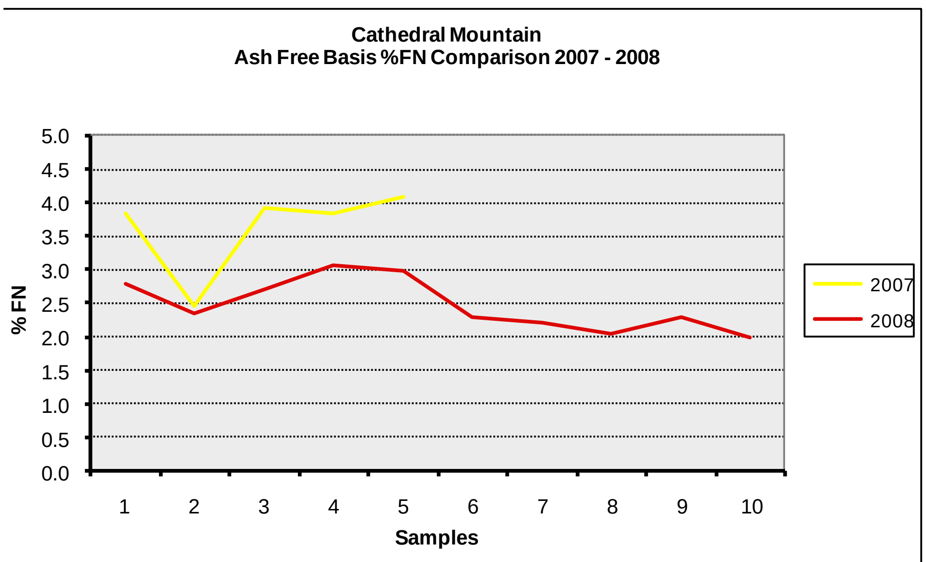
3.2 DAPA comparisons (ash-free basis).



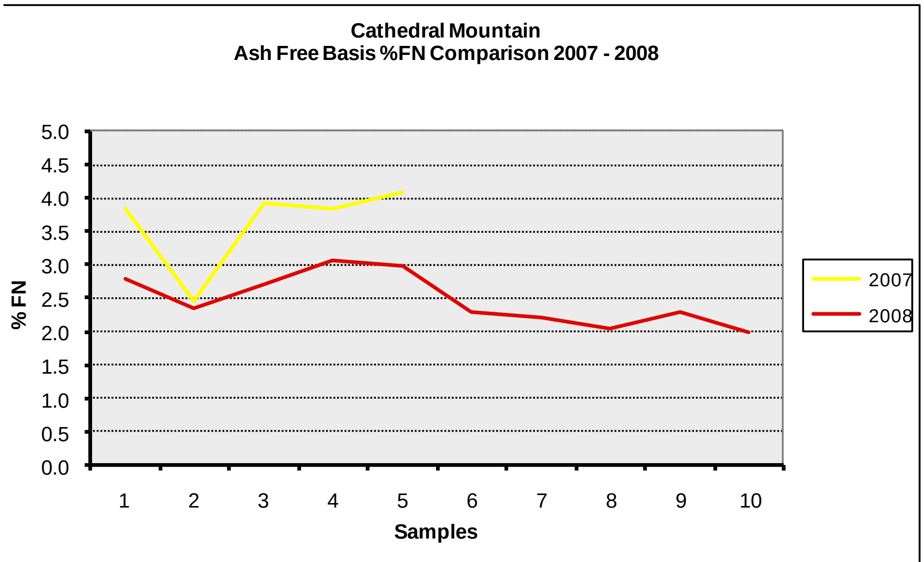
3.3 Percent FN comparisons (dry-matter basis).



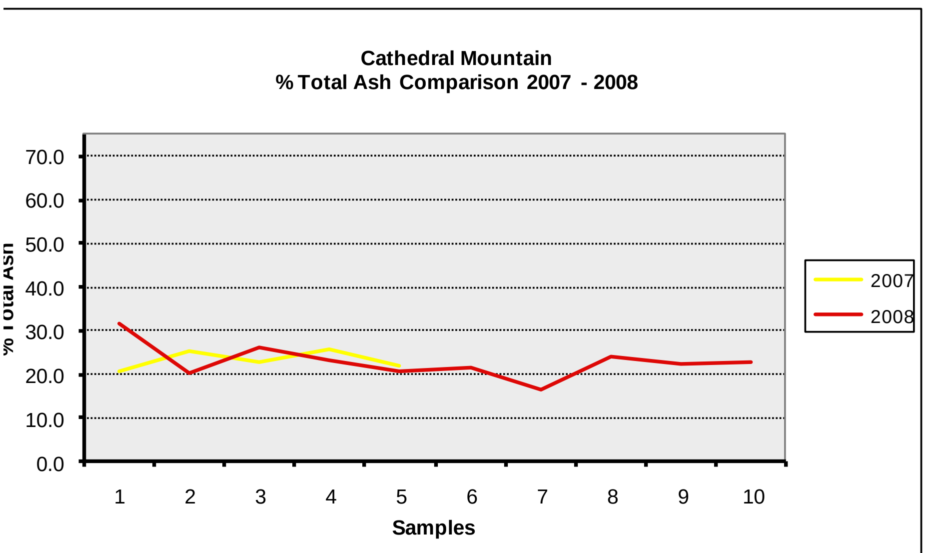
3.4 Percent FN comparisons (ash-free bassis).



3.5 Percentage of total ash comparisons.



3.6 Percentage of total ash comparisons.



Appendix 4. The student research undertaken by students in the Alaska Wildlands Program at the Wrangell Mountains Center described a set of alpine vegetation communities in the Mill Creek Valley of the Wrangell Mountains. In each plot the students identified the dominant community type, the three most abundant species within each canopy level, and the relative abundances of plants within quadrats (1 by 1m) at the 0m, 10m, and 20m marks along a transect. Results for the eight plots are given below.

4.1 Plot 1

Plot 01 Data Sheet **Date:** 7/24/08

Group leaders: Megan, Nicole, Erin **Field Techs:**

I. Orientation Information

SE Corner: -143.4765 61.555
Size: 30x30M **Slope Angle:** **Bearing:** True N/S

II. Community Type (30% dominance)

Type: Herbaceous
Comments: North facing slope (south of camp), east of willow plot

III. Top 3 Dominant Species

M. paniculata
Epolobium latifolium
Petasites sagitus

Quadrat Data Sheet Key: 1 = <10%, 2 = 10-25%, 3 = 25-50%, 4 = 50-75%, 5 = >75%

Species Names:		E. latifolium	M. paniculata	A. delphini-folium	Artemisa tilesii	Heracleum lanatum	A. umbellatus	Carex spp.	Lupinus arcticus	Anemone narcissiflora	delphinium glaueum	myosotis alpestris	Petasites sagitus	Grass	Moss
0M		3	3	1	2	1	1	1	1	1			3	2	
	Notes:														
5M		1	3	1	1					2	1	1	1	1	2
	Notes:	Some limestone in plot (< .5m in diameter) -- Level 2; Polemonium acutifolium -- Level 2													
10M		2	3	1	3		1	1		1			2	2	1
	Notes:	P. acutifolium -- 2													
20M		2	2	1	2		2	1	1	1	1	2	2	2	1
	Notes:	P. acutifolium -- 2													

4.2 Plot 2

Plot 02 Data Sheet **Date:** 7/24/08

Group leaders: Erin, Nicole, Megan **Field Techs:**

I. Orientation Information

SE Corner: -143.476 61.5546
Size: 30x30M **Slope Angle:** **Bearing:** N/S

II. Community Type (30% dominance)

Type: Shrub
Comments: Taller salix spp. Dominated plot; 2 species observed but u nidentified; North facing slope

III. Top 3 Dominant Species

Shrubs: salix spp. (> 10cm) **Herbaceous:** Lupinus arcticus
M. paniculata
E. latifolium

Quadrat Data Sheet Key: 1 = <10%, 2 = 10-25%, 3 = 25-50%, 4 = 50-75%, 5 = >75%

Species Names:		Death Camas	Lupinus arcticus	E. latifolium	M. paniculata	A. delphini-folium	Salix reticulata	Artemisia arctica	Anemone narcissiflora	Moss	salix spp. (taller shrub)	Petasites sagitus	Polemonium acutifolium	Delphinium glaueum
0M		1	4	2	1	1	4	1	1	1				
	Notes:													
5M														
	Notes:													
10M		1	2		1	1			1	100%	1	1	1	1
	Notes:													
20M														
	Notes:													

4.3 Plot 3

Plot 03 Data Sheet

Date: 7/25/08

Group leaders: Nicole, Erin, Megan

Field Techs: Matt, Vanessa

I. Orientation Information

SE Corner: -143.4729 61.5587

Size: 30x30M

Slope Angle: ~30'

Bearing: True N/S

II. Community Type (30% dominance)

Type: Shrub

Comments: Large meadow in middle of willow path; South facing slope

III. Top 3 Dominant Species

Shrubs: salix spp.
P. fruticosa
S. reticulata

Herbaceous: grasses
sanguisorba stipulata
artemisia arctica

Quadrat Data Sheet

Key: 1 = <10%, 2 = 10-25%, 3 = 25-50%, 4 = 50-75%, 5 = >75%

Species Names:		Salix spp.	Geranium erianthum	sanguisorba stipulata	Aquilegia formosa	Artemisia arctica	Grass/ Sedge	Salix reticulata	Lupinus arcticus	E. latifolium	Pyrola minor	Dryas Octopetala	Empetrium nigrum	Moss
0M		3	2	2	1	1								
	Notes:													
5M														
	Notes:													
10M			2			2	4	2	1	1	2	2	2	3
	Notes:													
20M		1	1		0	2	3	1	1	1			2	1
	Notes:	Bare soil 10-20%												

4.4 Plot 4

Plot 04 Data Sheet

Date: 7/25/08

Group leaders: Meg, Nicole, Erin

Field Techs: Vanessa, Matt

I. Orientation Information

SE Corner: -143.4732 61.5592

Size: 30x30M

Slope Angle:

Bearing: True N/S

II. Community Type (30% dominance)

Type: Shrub

Comments: N/NW plot 3 -- south facing slope

III. Top 3 Dominant Species

Shrubs: E. nigrum
D. octopetala
S. reticulata

Herbaceous: grass
Lupin.
moss

Quadrat Data Sheet

Key: 1 = <10%, 2 = 10-25%, 3 = 25-50%, 4 = 50-75%, 5 = >75%

Species Names:		Empetrium nigrum	D. Octopetala	Grass/ Sedge	Artemisia arctica	Geranium erianthum	E. latifolium	Moss	Lichen	V. uliginosum	Moss campion	Sorrel	Lupine	Potentilla fruticosa
0M		5	2	2	1	1	1	1	1	1				
	Notes:	crowberry -- berries; crainsbill -- no flower; dryas @ seed; limestone < .5m (1)												
5M														
	Notes:													
10M		4	3	1	1	1	1	1	1	1	1	1		
	Notes:													
15M		2	2	1	1	1		1		2			2	1
	Notes:													
20M		2												
	Notes:													

4.5 Plot 5

Plot 05 Data Sheet

Date: 7/25/08

Group leaders: Megan, Erin, Nicole

Field Techs: Vanessa, Matt

I. Orientation Information

SE Corner: -143.4741 61.56057

Size: 30x30M **Slope Angle:** **Bearing:** True N/S

II. Community Type (30% dominance)

Type: (none indicated)

Comments: Cassiope had an awesome scent! South facing slope, on west facing knoll side

III. Top 3 Dominant Species

Shrubs: Cassiope stellenana

Herbaceous: Anemone narcissiflora; E. latifolium

Unvegetated description: rocky, wet facing, rocks have veg. co

Quadrat Data Sheet

Key: 1 = <10%, 2 = 10-25%, 3 = 25-50%, 4 = 50-75%, 5 = >75%

Species Names:		Cassiope	Lichen	E. latifolium	Anemone narcissiflora	Equisetum variegatum	Lycopodium	Artemisia arctica	Moss	Grass/ Sedge	Salix Arctica	W. buttercup		
0M		5	1	1	1	1	1	1	2	1	1			
	Notes:													
5M														
	Notes:													
10M		5	1	1	1	1		1	2	1	1	1		
	Notes:	75% rock, limestone well vegetated, <=.8m diameter												
20M		3	2		1	1			4	3	1			
	Notes:	rock, veg covered, > 1M in diameter												

4.6 Plot 6

Plot 06 Data Sheet

Date: 7/25/08

Group leaders:

Field Techs: Vanessa

I. Orientation Information

SE Corner: -143.4742 61.56186

Size: 30x30M **Slope Angle:** **Bearing:** True N/S

II. Community Type (30% dominance)

Type: Herbaceous

Comments: 10-25% rock > 1M, south facing slope

III. Top 3 Dominant Species

Shrubs: S. reticulata; salix spp.

Herbaceous: sanguisorba stipulata; Ranunculus occidentalis

Quadrat Data Sheet

Key: 1 = <10%, 2 = 10-25%, 3 = 25-50%, 4 = 50-75%, 5 = >75%

Species Names:		sanguisorba stipulata	Crainsbill	W. buttercup	Artemisia arctica	Grass/ Sedge	Salix reticulata	Anemone narcissiflora	Petasites sagitus	Veronica wormskjoldii	Equisetum arvense	E. latifolium	Jacob's Ladder
0M		3	1	2	2	2	2	2	0	1	1		
	Notes:	< 1M in diameter highly vegetated rock											
5M													
	Notes:												
10M		5	1	2	0	3	1	1	2	1	1	1	1
	Notes:												
20M		5	1	1	0	3	1		2		1	1	
	Notes:	bog/wetland environment											

4.7 Plot 7

Plot 07 Data Sheet

Date: 7/25/08

Group leaders: Vanessa, Meg, Nicole

Field Techs:

I. Orientation Information

SE Corner: -143.4725 61.56035

Size: 30x30M **Slope Angle:** flat knoll top **Bearing:** True N/S

II. Community Type (30% dominance)

Type: (none indicated)

Comments: old sheep scat present, south facing slope

III. Top 3 Dominant Species

Shrubs: E. nigrum, Vaccinium spp., D. octopetala

Herbaceous: grass/sedge, Lycopodium, Lichen

Quadrat Data Sheet

Key: 1 = <10%, 2 = 10-25%, 3 = 25-50%, 4 = 50-75%, 5 = >75%

Species Names:		Lycopodium	Artemisia arctica	Gentiana glauca	S. Alpini	Dryas octopetala	Castillega	Grass	Anemone narcissiflora	Salix reticulata	Moss	Lichen	Vaccinium	Moss campion	Pedicularis spp.
0M		4	1	1	1	1	1	1	2	1					
	Notes:														
5M															
	Notes:														
10M						4		5	1	1	1	2			
	Notes:	< 10 bare rock, limestone													
20M						4		2		2	2	5	3	1	1
	Notes:														

4.8 Plot 8

Plot 08 Data Sheet

Date: 7/26/08

Group leaders: Erin, Nicole

Field Techs: Steve

I. Orientation Information

SE Corner: -143.4712 61.562158

Size: 30x30M **Slope Angle:** ~45 deg. **Bearing:** True N/S

II. Community Type (30% dominance)

Type: (none indicated)

Comments: south facing slope; old scat found in plot

III. Top 3 Dominant Species

Shrubs: S. reticulata

Herbaceous: sanguisorba stipulata, anemone narcissiflora, E. latifolium

Unvegetated description: ~50% rock slide; ~< .5M - 1M

Quadrat Data Sheet

Key: 1 = <10%, 2 = 10-25%, 3 = 25-50%, 4 = 50-75%, 5 = >75%

Species Names:		E. latifolium	Forget-Me-Not	Anemone Narcissiflora	Grass	Salix rotundifolia	Moss	Artemisia arctica	Equisitum variegatum	Sorrel	sanguisorba stipulata (garnet)	Salix reticulata		
0M														
	Notes:	100% rock < .5M (limestone), relatively resh slide, several snowmelt waterfalls												
5M		1												
	Notes:	75-100% (same as above)												
10M		1	1	4	1	2	4	1	1	1	1	4		
	Notes:	25-50% rock, some with established growth												
20M														
	Notes:													

Appendix 5. The following report was written by students in the Alaska Wildlands Studies Student Research Program at the Wrangell Mountains Center, under the direction of Dr. Megan K. Gahl (Director, Alaska Wildlands Studies Program). The students' research focused on characteristics of the preferred alpine-meadow habitat of sheep in the Upper Mill Creek Valley of Wrangell-St. Elias National Park. The report was prepared in the field and is a scanned version of their hand-written work.

Ed Pfeiff

DALL SHEEP IN THE UPPER MILL CREEK VALLEY:

An analysis of vegetation composition and range in *Ovis dalli dalli* habitat

STUDENT FINAL REPORT FOR THEIR FINAL PROJECT

SUMMER 2008

Nicole C. Chatterson, David Conner, Erin Conner-Diven
Ryan Edwards

8/7/08

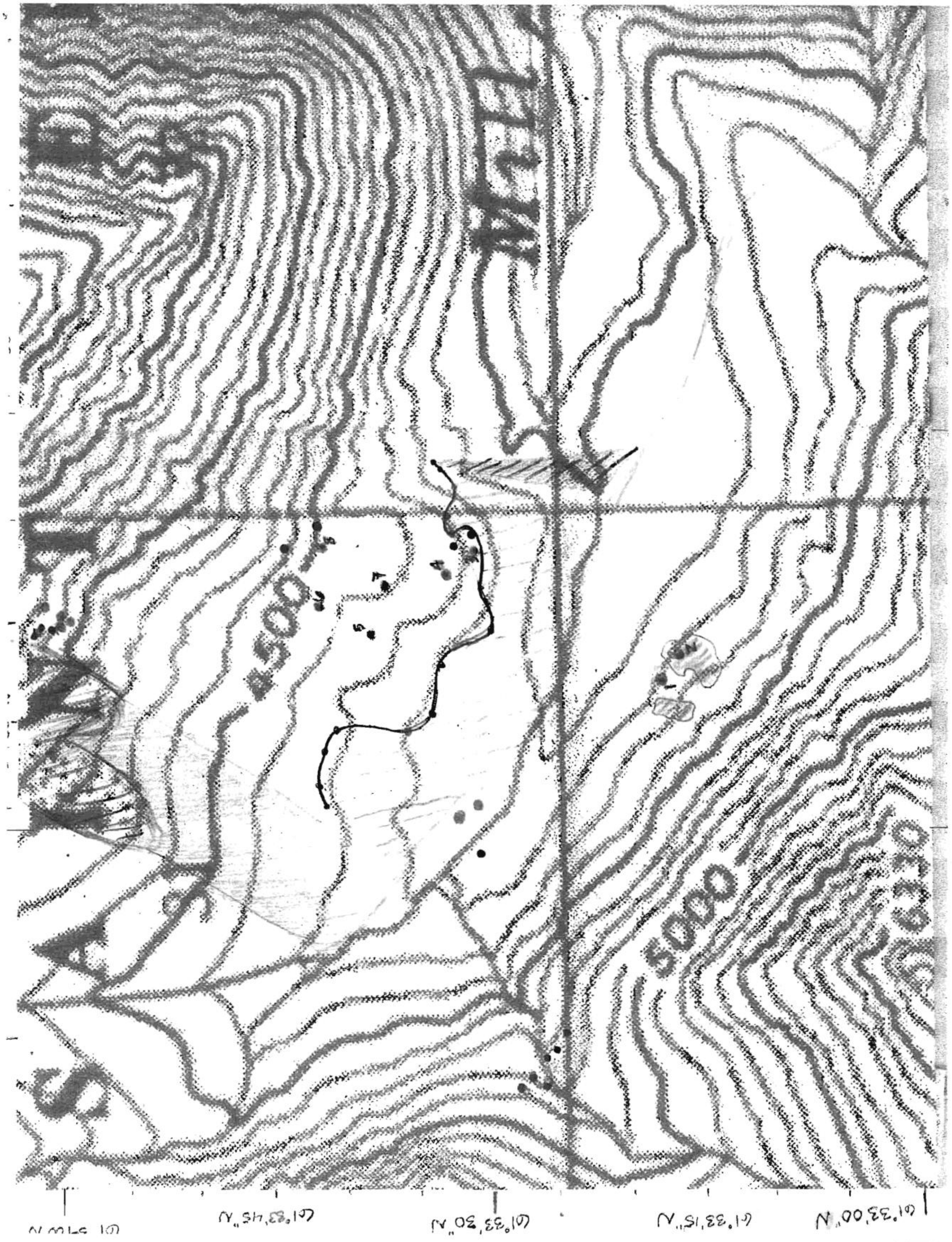
Wrangell Mountain Center, Wildlands Studies

Introduction:

Climate change is a global phenomenon and is known to cause major fluctuations in glaciation. The effects of the resulting deglaciation are being felt both world wide and, more specifically, in northern latitudes where much of the land is covered all or most of the year by ice. Species adapted to living in glacial habitats are especially sensitive to climate change. This retreat in glaciation is causing the range of vegetation communities in these latitudes to shift and can potentially cause a shift in the range of other species that depend on this vegetation such as the Dall Sheep, Ovis dalli dalli.

O. dalli dalli is a member of the Bovidae family and is found in the upper northwest territories of the North American continent - Alaska, Yukon, and British Columbia. Usually ~1 meter in length and ~275kg in weight, both sexes have horns that are never shed and are not branched. They prefer habitats located in extremely sloped mountains and are most often seen in bands of 6 or more (Burt et al. 1961). The primary predators of sheep, besides human hunters, are the lynx, wolverine, coyote, timber wolf, and grizzly bear. To escape these predators, sheep use their superior climbing ability to disappear over dangerous crags at a speed much faster than their predators (Dufrense 1955).

In order to gauge how sheep are affected by climate change, Ed Pfeiffer et al. (USGS) are researching the extent of sheep habitat change as local glaciers recede. In conjunction with this macro scale project we conducted a more focused study into the characteristics of the preferred alpine-meadow habitat of sheep. We used evidence of sheep presence such as scat or tracks to identify habitats with more sheep use. We


4500
5000
61°33'45"N
61°33'30"N
61°33'15"N
61°33'00"N

hypothesized that an equal amount of sheep scat would be found in all vegetative communities throughout the study area.

Methods:

Study Site

Our study site was the upper Mill Creek Valley centered at 61°34'00" N and 143°29'00" W to the northwest of McCarthy, AK. The elevation ranges from ~1200 meters at the valley floor to ~2100 meters at the surrounding mountain peaks. The upper end of the valley trends northwest - south east ~~beggin~~ beginning at two glaciers to the north and northwest and bounded by the Lakina River to the southeast. Our study focuses on the north-facing slopes of the valley made of Nizina Limestone and McCarthy Formation and the south-facing slopes made of Chitistone Limestone. Both are characterized by alpine-meadows and some shrub-zones (Fig. 5). Our study was conducted from July 23-26, 2008. Our base camp was on the south side of the river and contained 14 people.

Vegetation Boundaries

We defined shrub-zone as a vegetation area covered by at least 50% woody shrub of 1 meter or taller and alpine-meadow zone as a vegetation area covered by less than 50% woody shrub. We recorded latitude/longitude coordinates at 20 meter intervals along the shrub/alpine-meadow boundary using GPS (Garmin 72). To account for poor satellite reception caused by bad weather and rugged topography, we plotted our GPS points on a USGS topographic map (Mill Creek Watershed, 1:63,000 7.5 minute) to calculate elevation.

Scat Collection

To collect sheep scat, we surveyed the Mill Creek Valley slopes using broad east-west sweeps on the north- and south-facing slopes until because of steepness, the terrain became inaccesible. We used GPS to record the location of sheep scat piles that contained a minimum of 10 pellets. To differentiate fresh scat from previous seasons, we broke open pellets and tested for moisture. New scat was labeled SSN (Sheep Scat New) and previous season's scat was labeled SSO (Sheep Scat Old). Each sample was then numbered in ascending order, and fresh scat was placed in labeled canvas bags and shipped to USGS for nutritional analysis.

Vegetative Community Survey

We surveyed the composition of the vegetative communities in the upper Mill Creek Valley on both the north- and south-facing slopes using 8 plots, each 30m × 30m. The plots were oriented true north-south using a hand held compass. We then measured a transect oriented true north-south through the plot running from midpoint to midpoint. ~~1m²~~ We placed 1m² quadrats at 0m, 10m, and 20m along the eastside of the transect. Using GPS we recorded the latitude/longitude coordinates of each corner of the plot as well as the start and end points of the transect. We identified the overall community type within each plot as: tree, shrub, or herbaceous. Community type was defined as 30% coverage or more by the tallest canopy level, and we identified the three most abundant species within each level. The species within each quadrat along the plot transect were identified and each species was assigned a percentage range based on ground cover within the quadrat: 1 = < 10%, 2 = 10-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%.

In addition to the 8 plots, 2 separate $1m^2$ quadrats were set up near the snowline on the south-facing valley wall. We were unable to run a 30m x 30m plot in these areas because of slope steepness. The plots were oriented true north-south and the dominant species were identified and assigned a percentage cover as described before. For analysis, we divided the plots into 2 categories: sheep scat present and not present. We computed mean ground cover for each plant species within these categories from our quadrat data.

Results:

Vegetation Boundaries

Shrub areas were dominantly willow, Salix spp., throughout the upper valley. The north-facing slope was predominantly alpine vegetation such as low-lying shrub less than 10cm tall. The 2 outliers were willow islands at mean elevations of 1291m and 1312m with diameters of 470m and 220m respectively. (Fig. 5). The south-facing slope had a well defined shrub/alpine-meadow boundary at a mean elevation of 1280m (Fig. 4). The shrub-zone was confined laterally by a glacial moraine to the west and a limestone rockslide to the east. The valley floor surrounding the creek contained primarily willow on both sides at a mean elevation of 1235m.

Scat Collection

With the exception of 3 samples of sheep scat found on the valley floor, all scat samples were found above the shrub-alpine meadow boundary (Fig. 3). On the south-facing slope we found 5 fresh scat samples and 7 samples from previous seasons. All 5 of the fresh samples were found above our observed snowline (Fig. 3). ~~3~~ Of the previous season scat samples, 3 were found above the snowline and 4 were found below. We found 6 scat samples from previous seasons but no new scat on the north-facing slope. On the valley floor we found 2 scat samples from previous seasons and 1 new scat sample. An established sheep trail was found near the previous season's scat samples on the north-facing slope, and recent beds characterized by melted snow, and soil disturbances, were found near the fresh scat located at higher elevations on the south-facing slope.

Vegetative Community Survey

Of the plots on the north-facing slope, 1 was herbaceous, 1 was shrub. On the south-facing slope 1 was herbaceous, 4 were shrub, and 1 plot was unvegetated limestone (rockslide scree ≤1m). Both of the single quadrats were herbaceous communities (Fig. 1). We identified 45 individual plant species within the 8 plots and 2 individual quadrats. Of the 45 species, 7 were found exclusively in plots where scat was present, 25 were found exclusively in plots where scat was not present, and the remaining 13 were found in plots both with and without scat (Fig. 2).

The average richness within each plot was 14 species with a minimum of 12 and maximum of 16. While the average richness was similar among all plots, scat-present plots had an overall lower diversity because of reoccurring plant species such as *Salix reticulata* and *Dryas octopetela*. In general, the north-facing slope was less diverse than the south-facing slope (Conner, 2008)

Discussion:

We found that sheep scat was not evenly distributed among vegetation communities in the upper Mill Creek Valley. Higher abundance of sheep scat was strongly correlated with higher elevation (Fig. 4). This is consistant with previous research observations that sheep inhabit steep slopes at higher elevations (Geist 1971).

Plant diversity was low in scat-present plots relative to non-scat plots. Scat-present plant species were dominantly low-lying shrubs, particularly D. octopetela and S. reticulata. Because sheep are known to be specific grazers (Geist 1971), this correlation could explain why particular plant species (i.e. food sources) were reoccuring. Although scat was not found on the north-facing slope, characteristic of relatively low plant diversity, the presence of previous season's scat suggests that sheep may use this slope as vegetation accessability changes throughout the year.

While we found multiple scat samples from various seasons, limitations did arise preventing a more thourough sweep of the valley. Weather conditions including an unusually low snowline hindered our ability to locate scat in higher elevations that may have otherwise been visible. Low lying clouds and rugged topography also interferred with satellite reception causing inconsistancy with our GPS units. The presence of our large group in the study area may have had an affect on sheep occupancy of the valley during the time of our field work.

Although our data were limited to 4 days of field work, it can be used in conjunction with ongoing research in Denali National Park and serve as a basis for future research in the Mill

Creek Valley. To ensure accuracy and completeness, future work for this project should be conducted in small, less intrusive groups. To account for the time scale of climate change, the research should be conducted perennially over many consecutive years to descriptively observe affects on vegetation boundaries and communities that may correspondingly change sheep habitats.

Acknowledgements:

This paper is dedicated to Megan Gahl. Her guidance and high spirits were pivotal to the success of our project. We would like to thank Bill Morris for nourishing our budding plant identification skills and for his unwavering dedication to The S.F. Society. Many thanks to our wonderful friends for all of their help in the field: Leif Mjos, Dave Mitchell, Michael Suttner, Devin Coogen, Vanessa Cunningham, Matt Holkeboer, Steve Morten. We thank the Wrangell Mountain Center and staff for providing an exceptional learning environment: Jessica Speed, Jared Steyaert, Kirsten Miller, Vanessa Milcox, Tim Bartholamus, and the Godfather Ben Shaine.

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: PLOT & QUADRAT OVERVIEW

PLOT NO.	ELEVATION* (m)	DOMINANT SHRUB	DOMINANT HERBACEOUS	UNVEGETATIVE DESCRIPTION
1 erbaceous rth facing	1294 m		1. M. paniculata 2. E. latifolium 3. P. sagitus	
2 shrub rth facing	1293	1. Salix spp.	1. L. arcticus 2. M. paniculata 3. E. latifolium	
3 shrub uth facing	1297	1. Salix spp. 2. P. fruticosa 3. S. reticulata	1. Carex / grass 2. S. stipulata 3. A. arctica	20 m quadrat → soil cover 10-20%
4 shrub uth facing	1325	1. V. uliginosum 2. D. octopetala 3. S. reticulata	1. Carex/grass 2. L. arcticus 3. Bryophyte	< 10% limestone < 0.5m in diameter in quadrat #2 (10m
5 shrub uth facing	1343	1. C. stelleriana	1. A. narcissiflora 2. E. latifolium	10m quadrat → 75% rock cover, limestone with veg. cover, < 0.5 m in diameter 20 m quadrat → rocks, well vegetated, >1m in diameter
6 erbaceous uth facing	1346	1. S. reticulata 2. S. arctica	1. S. stipulata 2. R. occidentalis	0 m quadrat → < 1 m in diameter limestone
7 shrub th facing	1361	1. E. nigrum 2. V. uliginosum 3. D. octopetala	1. Carex/grass 2. Lycopodium 3. Lichen	
8 herbaceous uth facing	1377	1. S. reticulata	1. S. stipulata 2. A. narcissiflora 3. E. latifolium	~ 50% of plot dominated by rock slide, limestone ≤ 1 m in diameter

* Elevations shown here are the average of the "Transect End" and "Transect Start" elevations for each plot

EPSCAT QUADRAT	ELEVATION^Δ (m)	DOMINANT SHRUB	DOMINANT HERBACEOUS
SN-01 South facing shrub	1500 m	1. D. octopetala 2. S. reticulata	1. Carex/grass 2. S. acaulis 3. Lichen
N-05 th facing shrub	1500	1. S. arctica 2. S. rotundifolia	1. E. variegatum 2. A. richardsonii 3. Lichen

Δ Elevations shown here were taken at the specific location

FIGURE 1 Summary of the study sites within Upper Mill Creek Valley, including location (north or south-facing slope), community type (herbaceous or shrub), elevation, dominant species, and a description of any unvegetative observations within the site. Plots and quadrats outlined in bold indicate proximity to scat findings.

: 1 = <10% 2 = 10-25% 3 = 25-50% 4 = 50-75% 5 = >75%

SPECIES	SCAT NOT PRESENT AVERAGE COVER	RANGE*	NO. OF QUADRATS	SCAT PRESENT (within 5m of plot) AVERAGE COVER	RANGE*	NO. OF QUADRATS	COMMON NAME
...mone narcissiflora	4.44%	0-2	11/18	9.06%	0-4	3/8	Windflower
...emone richardsonii				7.8%	0-4	1/8	Yellow Anemone
...temesia arctica	7.1%	0-2	13/18	8.4%	0-4	2/8	Frigid Wormwood
Carex / grass	17.5%	1-4	18/18	10.3%	0-3	5/8	
...stilleja unalaschensis				0.6%	0-1	1/8	Paintbrush
...ryas octopetala	5%	0-3	4/18	27.2%	0-5	4/8	
...pilobium latifolium	7.5%	0-3	13/18	3.5%	0-2	3/8	River Beauty
...quisetum variegatum	0.8%	0-1	3/18	11.6%	1-5	2/8	Scouring Rush
...entiana glauca				0.6%	0-1	1/8	Gentian
Lichen	1.9%	0-1	7/18	15.9%	0-5	4/8	
Lycopodium spp.	0.3%	0-1	1/18	7.8%	0-4	1/8	
Bryophyte	11.3%	0-4	5/18	10.6%	0-4	3/8	Moss
...xyria digyna	0.3%	0-1	1/18	0.6%	0-1	1/8	Sorrel
...dicularis spp.				0.6%	0-1	1/8	Lousewort
Salix arctica	1.8%	0-2	4/18	4.7%	0-3	1/8	Arctic Willow
...alix reticulata	6.2%	0-4	7/18	15.3%	0-4	4/8	Dwarf Willow
...alix rotundifolia				6.9%	0-3	2/8	Roundleaf Willow
Silene acaulis	0.3%	0-1	1/18	1.3%	0-3	2/8	Moss campion
Solidago				0.6%	0-1	1/8	Goldenrod
...ccinium spp.				4.7%	0-3	1/8	Blueberry
...contium delphinifolium	1.7%	0-1	6/18				Monkshood

FIGURE 7 Each of the 45 species identified within the study sites are categorized by average percentage cover through either or both of the following two categories: scat present (within five meters of site) or scat not present.

	SCAT NOT PRESENT			SCAT PRESENT (within 5m of plot)			
SPECIES	AVERAGE COVER	RANGE*	NO. OF QUADRATS	AVERAGE COVER	RANGE*	NO. OF QUADRATS	COMMON NAME
Aquilega formosa	1%	0-2	1/18				Columbine
Aretastaphylos alpina	1%	0-2	1/18				Bear Berry
Arnica alpina	1.3%	0-2	2/18				Alpine Arnica
Artemesia tilesii	5.6%	0-3	6/18				Wormwood
Astragalus umbellatus	1.5%	0-2	3/18				Hairy Arctic Milk Vetch
Cassiope stelleriana	11.8%	0-5	3/18				Moss Heather
Delphinium glaucum	0.8%	0-1	3/18				Larkspur
Empetrum nigrum	11.3%	0-5	5/18				Crow Berry
Equisetum arvense	0.8%	0-1	3/18				Horsetail
Geranium arianthum	3.9%	0-2	9/18				Crane's Bill
Heracleum lanatum	0.3%	0-1	1/18				Cow Parsnip
Lupinus arcticus	6.5%	0-4	7/18				Lupine
Mertensia paniculata	7.1%	0-3	6/18				Bluebell
Myosotis alpestrius	0.6%	0-1	2/18				Forget-Me-N
Petasites sagitus	6.5%	0-3	7/18				Coltsfoot
Polemonium acutiflorum	0.6%	0-1	2/18				Jacob's Ladde
Potentilla fruticosa	0.6%	0-1	2/18				Cinquefoil
Pyrola minor	0.3%	0-1	1/18				Lesser Wintergreen
Ranunculus occidentalis	2.5%	0-2	4/18				Western Buttercup
Salix spp.	7.2%	0-5	3/18				Willow
Sanguisorba stipulata	12.8%	0-5	4/18				Sitka Burne

FIGURE 2

	SCAT NOT PRESENT			SCAT PRESENT (within 5m of plot)			
SPECIES	AVERAGE COVER	RANGE*	NO. OF QUADRATS	AVERAGE COVER	RANGE*	NO. OF QUADRATS	COMMON NAME
/accinium uliginosum	1.5%	0-2	3/18				Bog Berry
eronica wormskjoldii	0.6%	0-1	2/18				Alpine Veronica
ygadenus elegans	0.6%	0-1	2/18				Death Camas

FIGURE 2

CONTRASTS BETWEEN NORTH & SOUTH-FACING SLOPES

		NORTH-FACING SLOPE	SOUTH-FACING SLOPE
ABIOTIC	Land / rock slides	· limestone present in slide · avalanches · more active slides than south-facing side	· larger clasts than north-facing side · avalanches · most slides covered with vegetation
	Glaciers		X
	Sun exposure	· sunlight later in the season · light blocked by topography	· sunlight earlier in the season · more sunlight during the season due to sun's high obliquity at this latitude
	Parent material for soil	· Nzina stone & McCarthy formations	· Chitistone limestone
	Topography	· mostly just one uniform steep slope	· rolling landscape with lots of knolls until higher elevations where there were steep slopes and cliffs
BIOTIC	P. fruticosa		X
	Ranunculus occidentalis		X
	M. paniculata	X	
	C. stelleriana		X
	Vaccinium spp.	X	
	S. rotundifolium	X	
	H. lanatum		X
	Solidago spp.	X	
	P. minor		X
	E. nigrum		X
	G. arianthum		X
	Sheep Scat	· ONLY OLD SCAT found on slopes · two new scats found on south side of valley floor	· new scat found high on slopes · old scat found high on slopes and in lower slopes and knolls

FIGURE 3 Summary of observed abiotic and biotic differences between the north and south-facing slopes of the study site. An (X) indicates presence on the respective slope. The species listed were found exclusively on either of the two slopes.

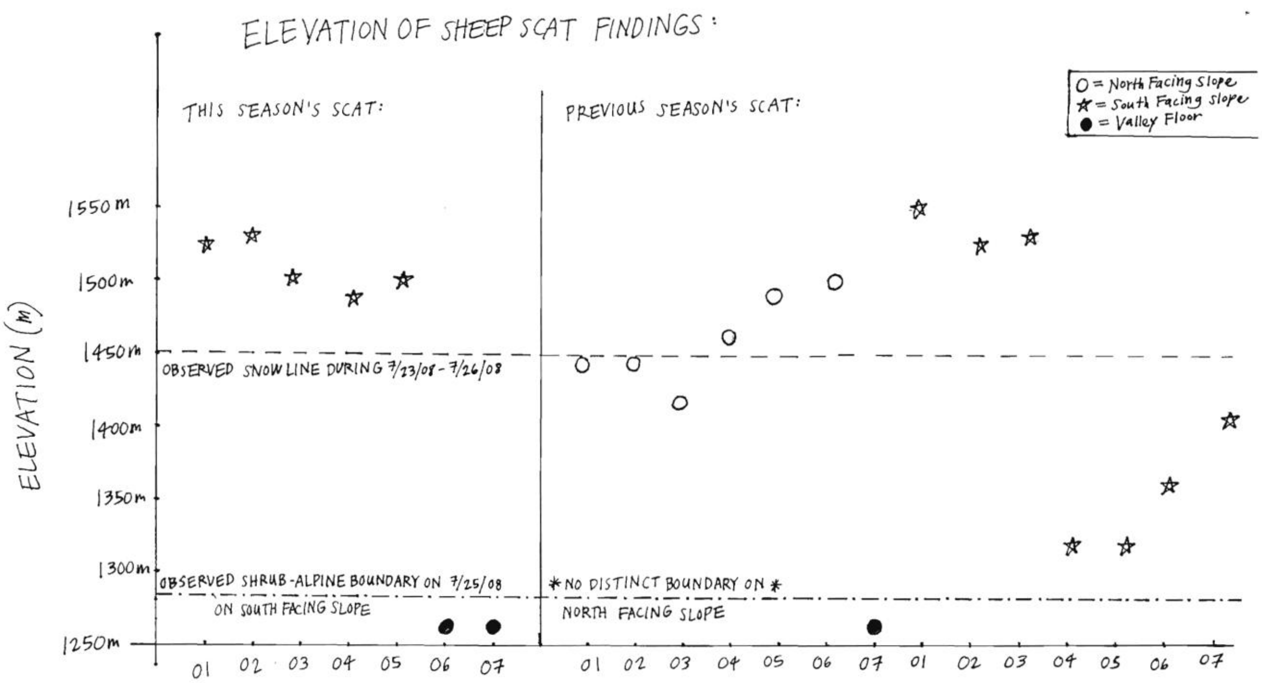

FIGURE 4 This graph delineates between this season's scat and previous season's scat as well as the elevations at which they were found

Figure 5 : Topographic map of study site including: the location of scat findings, plot and quadrat locations, the shrub-alpine boundary of the south-facing slope and the shrub islands on the north facing slope.